Vol. 26, No. 151 MAY, 1942 JUN 15 1942 Price 2/- [Subscription 24/- per annum post free]

METALLURGIA

THE BRITISH JOURNAL OF METALS

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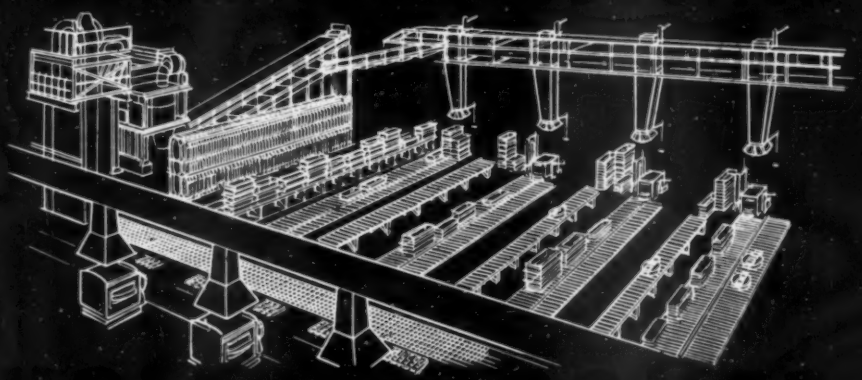

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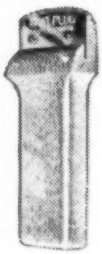

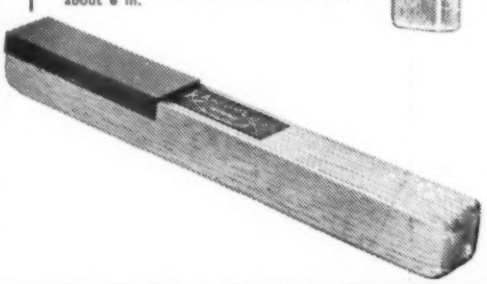

METALLURGIA

The British Journal of Metals

(INCORPORATING THE METALLURGICAL ENGINEER.)

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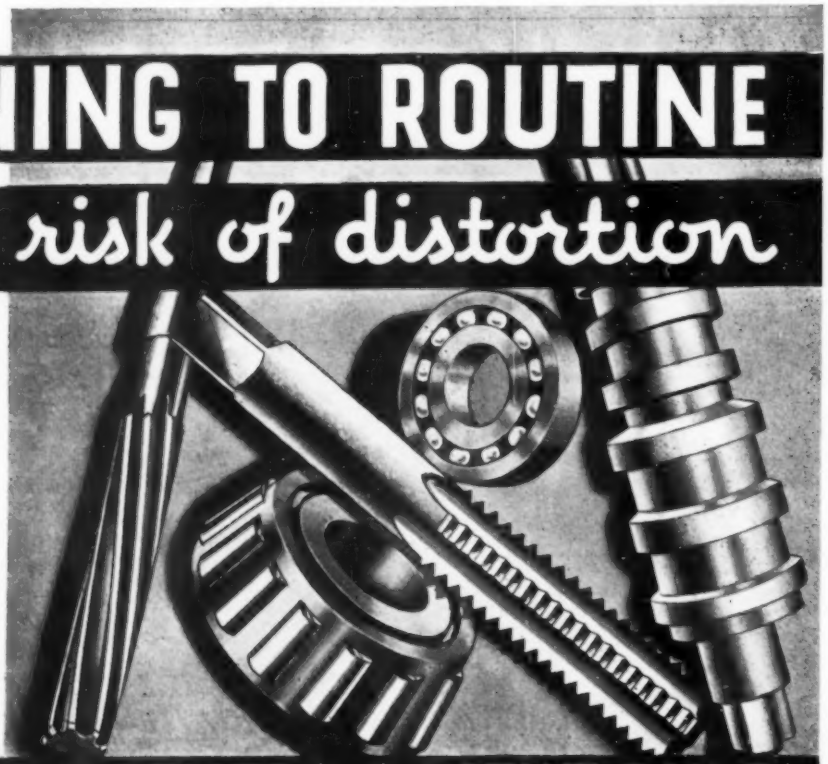

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METALLURGIA

THE BRITISH JOURNAL OF METALS.
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MAY, 1942. VOL. XXVI, No. 151.

Silicon Bronze for Sand Castings

By W Machin, M.I.Brit.F.

In view of the need for conserving supplies of tin, greater use is likely to be made of the silicon bronzes, and attention is directed more particularly to the silicon-iron-copper alloy P.M.G., which is available in a range of compositions suitable for work normally made in gunmetal, manganese bronze, or phosphor bronze. The subject was discussed at considerable length by Mr. Machin before a recent meeting of the Lancashire Branch of the Institute of British Foundrymen, in which he dealt with the manufacture of this alloy and the moulding technique involved in its use for castings. He prefaced his discussion with a consideration of some defects and their causes in the production of gunmetal and manganese-bronze castings, and some of the main features considered are given in this article.

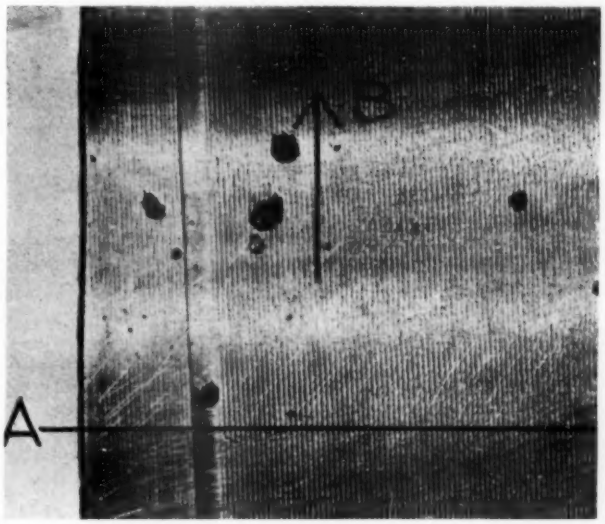
THE manufacture of castings in the numerous brasses and bronzes for shipbuilding and engineering requirements to-day is an industry built upon the solid and dependable foundation of experience. A formidable task it would be to outline even those difficulties personally encountered over many years, and certainly overwhelming to attempt to detail more than a fraction of the valuable information garnered by combined study, experiment, sometimes failure, and ultimate success.

Where a standard type of casting is concerned, it may be said that successful production is, to a great extent, due to an established method built up by individual experience, or to one of generally accepted practice, but the constantly changing nature of modern requirements repeatedly place before us new problems to be solved. Each phase in the making of a mould must be carefully considered in the light of results already obtained, and it can be assumed that the greater proportion of defective castings are caused by the workmen overlooking some small, but important, detail of procedure.

The composition, temperature and treatment of the metal are to be taken into account, factors which, accepted in their true perspective, are of the greatest importance in the production of sound castings. The technique of metal melting has been frequently considered, and, therefore, it is only necessary to touch upon that aspect of the production of castings, the object being to deal more particularly with the practical side of production by outlining some of the defects in brass and bronze castings as a preliminary to a consideration of silicon-bronze castings.

Prominent among the many non-ferrous metals at present in use are gunmetal and what is known as manganese bronze, and brief reference may be made to rejects and replacements in these alloys, as well as others, insofar as the moulding and other operations in the foundry are concerned. Defects brought about by faults in the moulding technique result in the rejection of castings, and frequently necessitate modification in the moulding method to overcome the difficulty. In many instances, however, even after alterations have been made to moulds and successful castings produced, further similar castings have been rejected, due mainly to some small, but important, detail having been overlooked.

Generally, more castings are defective and a correspondingly greater proportion rejected, through faults in the moulds and cores, than are associated with the melting operation. A few points in technique, which the moulder sometimes regards as unimportant, may be usefully stressed. The first was a gunmetal liner, which, apparently perfect when it left the foundry, proved to be defective when blowholes were revealed in the machine shop. The mould had been made by a competent moulder, a perfectly vented core was used, and apparently everything done to ensure a sound casting. The method employed was closely



Showing defective part of a gunmetal liner cast horizontally. The mould joint was at A, and the defect is caused through steam from moist loam, used as a stopping material in the joint, moving in the direction of B to the riser.

examined and the source of the trouble was revealed. The gap formed between the two parts of the mould had been stopped with loam to prevent the escape of molten metal when casting, and steam from the moist loam generated by the warm mould had been drawn through the mould joint towards the riser. This unsatisfactory practice has been the cause of this defect in numerous instances, although there is no real need to stop up joints in this manner. Other examples of a similar type, but with dry sand moulds, were cited and illustrated.

In all foundries making many different types of castings the temperatures of the moulds to be cast vary. If portions of a mould, or its cores, have been available for a few days after being dried and are cold when the mould is assembled, care should be taken that they have not absorbed moisture, otherwise the defect known as porosity may be caused.

Another type of defect, known as scabbing, is caused by sand becoming loosened from the face of the mould, or core, which subsequently becomes trapped against the mould, or cores, and is held by the metal. This type of defect can usually be found before the casting leaves the dressing shop.

It has been observed that many defects found in manganese bronze castings are due to slow running; this is evident from subsequent leakage of castings under pressure test and/or spongy patches in remote areas farthest away from the inlet to the mould from the main runners. Whenever possible manganese-bronze castings should be run from the bottom, and if more than one sprue is used to carry the metal to the mould they should be so placed that the metal from each should enter the mould in the same direction, and one down runner should connect the sprues. The use of a large runner basin, capable of holding enough metal to completely fill the mould is to be preferred. In this way the runner is sealed with a stopper, and the metal poured into the basin and the ladle removed before the stopper is lifted. The operation is carried out smoothly and without flurry, which is necessary to ensure that every detail of the casting technique is correct. Under these conditions the running of the casting is under more perfect control than when teeming the metal into a small basin direct from the ladle. The speed of filling the mould by this method is governed by the size of the sprues, but it permits fast running, which is preferred.

Many examples are given with a view to proving that the fast method of running high-zinc alloys is definitely better than the slow method. Less zinc oxide is accumulated by the former method, and, in addition, hotter metal is obtained in the feeders when the casting operation is complete, which permits better feeding of the casting as shrinkage proceeds. This method of casting is applicable to both gunmetal and manganese bronze.

In high-zinc alloys the amount of oxide formed is proportional to the temperature of the metal when exposed to the atmosphere. Generally, oxides are formed more rapidly at high-melting temperatures, and since it is necessary to prevent oxidation as much as possible, careful attention must be given to this important aspect. It is known, for instance, that tin oxide in a bronze reduces its tensile value. A good method is to keep the surface of the molten metal protected from the atmosphere by a covering of charcoal, glass or other suitable material. Although this practice reduces oxidation, it is necessary to cover the metal in the early stages of the melt.

The foregoing remarks on causes of defects apply also in the case of silicon bronzes, such as P.M.G. metal. The same care is necessary in the moulding and casting technique as is necessary with gunmetal, manganese bronze, high-strength brasses and phosphor bronze.

P.M.G. Metal

P.M.G. metal, in its various grades, is a silicon-iron-copper alloy, the standard mixture containing 88% copper, 10% hardener, and 2% zinc. It was developed with the intention of replacing ordinary gunmetal and similar bronzes, and the letters P.M.G. were intended to convey that the metal could be used instead of phosphor bronze, manganese bronze, or gunmetal. Its ultimate tensile strength values, in the cast and forged conditions, are superior; its application as a bearing metal is favourable in comparison with phosphor bronze.

In view of the need for conserving supplies of tin it is likely that this silicon bronze will be used more extensively, and, following long experience in its manufacture, it is thought advisable to give a short practical account of the methods of manufacture of this metal and to give some technical advice regarding its use in the production of castings.

The hardener previously mentioned is a substitute for tin, which it replaces in the standard composition. It is specially compounded and is a patented alloy, but arrangements can be made with Messrs. Vickers-Armstrong, Ltd., Barrow-in-Furness, for permission to manufacture this hardener under licence. It is composed of silicon, copper, iron and manganese. The special technique of manufacture was fully described. It is prepared in 100-lb. charges and, when molten, is cast into ingot moulds and allowed to cool, subsequently it is taken to the metal store to be weighed and used in the same manner as tin.

In preparing a charge to make the standard P.M.G. alloy to replace gunmetal, similar care is necessary as for the latter, the zinc being added after the copper and hardener has been melted. Melting is accomplished in about the same time as for gunmetal. No great care need be taken in the use of scrap, as 25% of P.M.G. scrap and 75% of P.M.G. metal borings has given as much as 24 tons/sq. in. ultimate tensile strength, with 12 tons/sq. in. yield, and 21% elongation, but the scrap must be P.M.G. metal, it must not be contaminated with gunmetal or phosphor bronze scrap, as the presence of tin is fatal to good results.

As regards the temperature at which it is considered best

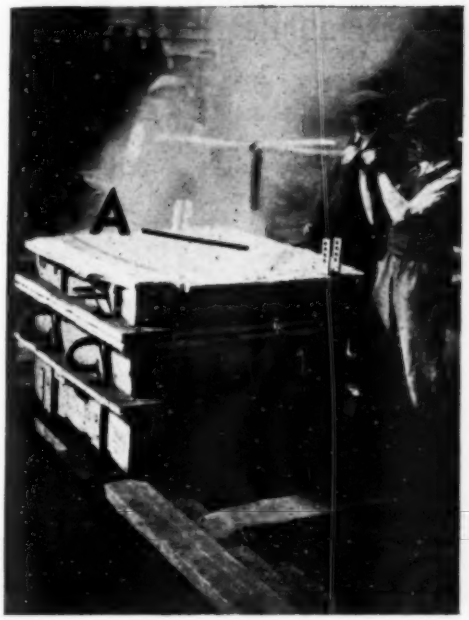
SOME RESULTS OF TESTS ON HEAT-TREATED P.M.G. METAL

CAST P.M.G.

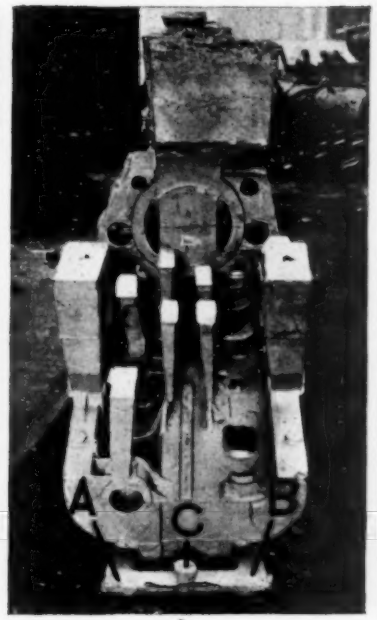
	Yield.	U.T.S.	Elongation on 2 in. %	Brinell.
Heated to 900° C.—				
(*a*) Slowly cooled	10·1	21·6	13	85
(*b*) Quenched in water	9·6	24·8	28	80
(*c*) Quenched in water. Reheated to 350° C. for 2 hours. Cooled in air	9·6	25·2	26	85
(*d*) Quenched in water. Reheated to 450° C. for 2 hours. Cooled in air	12·0	22·4	14	107
(*e*) Quenched in water. Reheated to 550° C. for 2 hours. Cooled in air	11·6	17·2	3	121
(*f*) Quenched in water. Reheated to 650° C. for 2 hours. Cooled in air	10·0	15·6	2	111
Heated to 800° C.—				
(*g*) Slowly cooled	9·6	21·2	13	101
(*h*) Quenched in water	10·0	21·2	13 O.P.	85
(*j*) Quenched in water. Reheated to 350° C. for 2 hours. Cooled in air	9·6	23·2	21	99
(*k*) Quenched in water. Reheated to 450° C. for 2 hours. Cooled in air	11·6	23·6	15 O.P.	101
(*l*) Quenched in water. Reheated to 500° C. for 2 hours. Cooled in air	12·4	20·4	7	107
(*m*) Quenched in water. Reheated to 650° C. for 2 hours. Cooled in air	10·0	21·2	15	101

FORGED P.M.G.

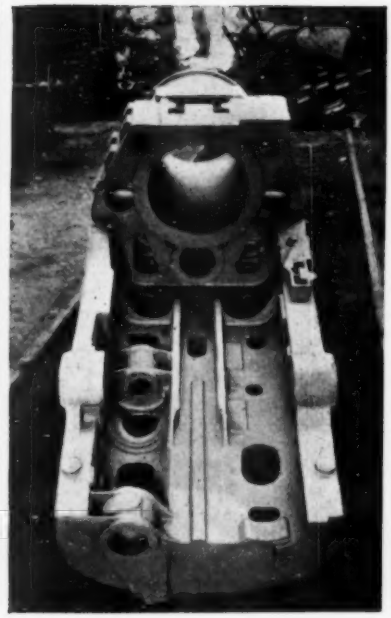
	Yield.	U.T.S.	Elongation on 2 in., %	Brinell.
Heated to 900° C.—				
(*a*) Slowly cooled	12·8	27·2	33	89
(*b*) Quenched in water	12·8	28·4	46	89
(*c*) Quenched in water. Reheated to 350° C. for 2 hours. Cooled in air	11·0	28·4	44	107
(*d*) Quenched in water. Reheated to 450° C. for 2 hours. Cooled in air	12·0	24·8	31	101
(*e*) Quenched in water. Reheated to 550° C. for 2 hours. Cooled in air	15·6	22·8	7	129
(*f*) Quenched in water. Reheated to 650° C. for 2 hours. Cooled in air	12·4	15·6	3	107
Heated to 800° C.—				
(*g*) Slowly cooled	14·0	31·2	48	113
(*h*) Quenched in water	14·0	30·8	37	107
(*j*) Quenched in water. Reheated to 350° C. for 2 hours. Cooled in air	15·2	31·2	45	121
(*k*) Quenched in water. Reheated to 450° C. for 2 hours. Cooled in air	15·2	31·2	48	113
(*l*) Quenched in water. Reheated to 550° C. for 2 hours. Cooled in air	17·2	32·8	36	121
(*m*) Quenched in water. Reheated to 650° C. for 2 hours. Cooled in air	14·0	31·2	48	107



The casting operation involving the use of a large basin—sometimes called a sow—which receives the whole of the metal required to fill the mould and feeders. Note the plug, or stopper, being lifted to permit the fluid metal to enter the mould.



The casting as taken from its mould, showing the runner inlets, or sprues, at A and B and the main down runner at C which connects them to the basin. Note the substantial risers which are required as feeders.



The finished casting after feeders and runners have been cut away. In this form it is transported to the machine shop, but only after careful inspection has failed to reveal defects.

to cast P.M.G. metal, the following figures may be of interest as regards test results from 950° to 1,300° C.

Casting Temperature, °C.	U.T.S., Sq. In., Tons.	Yield, Sq. In., Tons.	Elongation, % in 2 in.
1,300	23·2	11·2	16
1,140	23·2	10·8	19
1,100	24·4	11·2	20
1,050	25·2	12·4	21
1,000	18	12	4
950	16	12	3

It will be seen from the above figures that between 1,050° C. and 1,300° C. will give the foundrymen a very wide scope as regards thick and thin sections in a casting. This information will enable him to pick out a temperature to cast his work successfully.

Many and varied are the tests which have been carried out with P.M.G. metal; records of many tests are available which have been carried out by firms in all the industrial countries. They comprise the results of mechanical tests on alloys containing various percentages of zinc and copper, and from 1% to 10% of hardener. These include tests carried out on test bars cast in green sand, dry sand on forge material at various temperatures; on extruded bars and rolled sheet; compression, torsion, shear and fatigue tests; tests under various temperatures; corrosion erosion and resistance to corrosive media; and bearing tests. But apart from some data resulting from tests on heat-treated P.M.G. metal, given in the accompanying table, attention is more particularly directed to the handling of the metal during melting and in the subsequent casting operations; with this object a large number of castings of different types are briefly discussed.

Particular reference should be made to the contraction of castings in this silicon bronze. From experience it is found that P.M.G. metal contracts at a more rapid rate than do bronzes containing tin. Castings made in this alloy that are fairly long must be eased by loosening the sand about the feeders and runners immediately after solidification, especially dry sand moulds. Castings up to 25 ft. in length have been successfully made; but before the present technique was developed trouble was experienced with contraction cracks, these, however, disappeared after taking the precautions previously mentioned.

That a vast amount of work has been done on this alloy will be appreciated when it is stated that about 40,000 castings in this alloy were used in the completion of five ships built recently; the castings are applied to a very wide range of purposes, and they successfully satisfy exacting demands.

[We have been advised that arrangements are being made with one of the alloy manufacturers in this country to produce and market the special hardener used in the making of P.M.G. Metal, discussed by Mr. Machin. This hardener can be used as a substitute for tin in the compounding of many non-ferrous alloys; thus, for instance, it can be compounded with copper to replace tin in gun-metal, the amount being the same—i.e., 10% hardener instead of 10% tin—and the resultant alloy will meet the new Admiralty specification S.B. 20 for gun-mounting work.—EDITOR.]

Sheffield Metallurgical Association

THE above Association is holding a joint meeting at the Royal Victoria Hotel, on May 19, at 5-10 p.m., with the Sheffield Society of Engineers and Metallurgists, the Refractories Association, and the Iron and Steel Institute, to discuss dolomite bricks and open-hearth roofs. On May 26, at 7-30 p.m., the Association is holding a meeting, at which the subject under discussion will be "Any Questions," and members are asked to suggest subjects for discussion.

JAMES TAYLOR PRIZE

The Council is considering the award of the James Taylor Prize. This prize is awarded for the paper which, in the opinion of the Council, shows the greatest originality of conception or deals more usefully with some metallurgical subject of current interest. The prize is limited to members of the Association who are asked to send particulars of any publications in 1939-41 to Mr. L. Rotherham, 93, Hallowes Lane, Dronsfield, near Sheffield, before the end of June.

The Electrochemical Society

Eighty-First Convention Held at Nashville

THE technical discussions arranged for the above Convention, on April 15–18, opened with a session devoted to electric-furnace reactions, at which Dr. John D. Sullivan took a leading part. Included in the programme was a paper by Dr. Frank R. Kemmer, recently returned from Australia, who gave his views on the electric steel industry in the Commonwealth, particularly the new electric ferro-alloy plant in Newcastle. Another paper, by Mr. W. A. Darrah, concerned the application of the electric furnace to the steel industry of Brazil.

The electric furnace is largely responsible for big changes that have taken place in the steel industry during the last decade. Not only is it possible to operate at temperatures in excess of those possible by fuel-fired furnaces, but the atmosphere over the metal can be controlled and relatively little heat is wasted. It enables the production of high-grade steel and is especially valuable in the production of high alloy steels, such as stainless steel.

In the second session a number of papers were presented on electrochemical research. Attention was directed to the gradual changes being effected in the galvanising and tinplate industries by the adoption of modern electro-chemical methods. It is claimed that the best galvanised fence wire to-day is made electrochemically; while recently the United States Government ordered that the steel industries abandon the very wasteful hot-dip method for making tinplate in favour of the electrochemical method. About two-thirds of the tin is conserved in this way. Electro-tinplate is produced by depositing on a swiftly moving ribbon of steel about 2 ft. wide, passing through the plating solution, and using currents that are a hundredfold of those to which the old electroplater is accustomed.

Gradually, a change is taking place in the control of the electroplating industry in the United States; a few years ago the automotive industry took over the electroplating industry and laid down new and stringent specifications; to-day, however, the steel corporations are taking over the industry and revising these specifications. Instead of plating a million small parts after fabricating, the plating is now completed before the parts are fabricated, with a resulting saving in ultimate cost of the individual parts.

One session covered some of the latest developments in the field of corrosion. Among the subjects discussed was the so-called cathodic protection of pipe lines. This is particularly important at the present time, as leaks in oil or gas pipes must be guarded against. After many years of experiments and trials, designed to protect these pipes against corrosion, a very simple method has been installed for maintaining the pipes "cathodic." The procedure is very simple. An anode of cheap iron is embedded in the soil a few feet from the pipe and a current of about 6 to 7 volts is applied between the pipe and the anode. The iron anodes are spaced along the pipe-line at regular intervals depending upon the conductivity of the soil and other factors. This scheme of cathodic protection originated in the British Navy and was first applied to the boiler tubes. To-day the method is applied to a wide variety of apparatus that needs to be protected from rusting. In the case of boiler tubes, an additional interesting feature developed is that, as long as the boiler tubes are cathodically protected, no boiler scale is formed.

One of the most important metals in the present war is magnesium, and various aspects of this metal were discussed in two papers. Here again electro-chemists have contributed in the development of this metal. At the close of the last great war a little over 100 tons of magnesium metal per annum was being produced in the United States: to-day, production approaches 20,000 tons. On a bulk basis magnesium is one of the cheapest of metals, being third in the scale, with iron as the cheapest.

Water Power and its Application to the Production of Metals

MR. W. T. HALCROW (senior partner in the firm of W. T. Halcrow and Partners, successors to Messrs. P. W. and C. S. Meik) delivered the thirty-second annual May Lecture of the Institute of Metals, on May 13, in the hall of the Institution of Mechanical Engineers, Lieut.-Colonel Sir John Greenly, K.C.M.G., C.B.E., M.A., President of the Institute of Metals, being in the chair.

Mr. Halcrow said that water was a source of power from which electricity could be generated cheaply and in large quantity, and was therefore an important asset to the metallurgical industry, both in mining the ore and for reducing it to the finished metal. Outstanding engineering works have been constructed in many parts of the world to harness the immense resources which lie latent. The United States, Scandinavia and Russia have done much in this direction, and most European countries were gradually developing this industry. Great Britain was not so favourably placed for the production of water power owing to its geographical features, but important work had already been done.

In order that the best use be made of the untapped reserves throughout the world, especially in the British Empire, comprehensive inland water surveys were necessary. Electricity could be produced from water power at a cost below that produced by steam, and reference was made to the factors governing the cost in each case. Particulars were given of potential resources at home and abroad and the promotion of schemes in this country was discussed.

SPONGE CHROMIUM

Low-Temperature Reduction without Sintering in the Basis of the Process

A FORM of sponge, or powdered, chromium metal that under certain conditions attains a purity of 99·8%—higher than any chromium used in present commercial manufacturing—has been produced from both low- and high-grade domestic chromite ores, through a process developed by metallurgists of the Bureau of Mines. Immediate benefits of the improved form of chromium metal are expected to be the development of new and important alloying processes in the metal industries. Its high purity in powdered form render it valuable in the manufacture of special steels, brass and bronze materials, and in alloys that are subjected to high temperatures, such as electrical heating elements.

Successfully carried through the laboratory stage to a point where pilot plant tests are justifiable, the new reduction process may, under favourable circumstances, permit the utilisation of a large amount of America's "off-grade" chromite ores at costs comparable to the existing prices of low carbon ferrochrome. However, its future in this field will depend chiefly upon the availability and cost of chlorine, the chemical used extensively in producing this new metallurgical material.

Low temperature reduction without sintering is the basis of the process developed during five years of research and investigation, in obtaining pure chromium metal. The fundamentals consist of the chlorination of chromite ores at elevated temperature, sublimation and separation of volatile chlorides, and reduction of chromium to metal by hydrogen. Sponge chromium of at least 99% purity may be produced, and if specially purified chloride is used, the product may reach 99·8 purity.

Methods and formulas employed in the laboratory production of sponge chromium by the chlorine method are described in detail in "Sponge Chromium," by C. G. Maier, 109-page technical bulletin No. 436, soon to be published by the Bureau of Mines. Copies will be available at 20 cents each from the Superintendent of Documents, Government Printing Office, Washington, D.C.

METALLURGIA

THE BRITISH JOURNAL OF METALS.

INCORPORATING "THE METALLURGICAL ENGINEER"

Research in the Iron and Steel Industry

THERE must be very few engaged in the iron and steel industry who do not realise that the great march of industrial progress depends essentially on research. It is necessary to progress in every branch of industry, and the iron and steel industry is no exception. As Mr. Henderson pointed out in his presidential address, progress at the Lincolnshire works would not have been possible without research. It is true that the same can be said of all other districts producing iron and steel, but it has a special significance when applied to the Lincolnshire district, where very lean ores are used.

Although divergent views are frequently expressed on the subject of research, the majority of interested people will agree that it should be directed by the practical desire to improve the quality of the product and profitably to modify the process of manufacture. Individual iron and steel companies have made great progress in recent years in building up staffs and laboratories for research. As Mr. Henderson states, "every leading steelmaker in the country has, in addition to laboratories dealing with routine analyses and local problems, an organisation for the study of major problems and the development of new and improved products. These central research laboratories are in constant touch with the works and with works problems; they are very much concerned with production problems, and the value of their work would be greatly reduced if they were interested only in theory and pure science. On the other hand, the production staff at the works maintain close contact with the central laboratories, and most problems of importance are thrashed out jointly. To summarise, constant attention must be given by all responsible officials at works to details in the technique of production. At the same time, there must be keenness to experiment and the courage to risk failure by trying something new. There must also be constant endeavour to satisfy the customer, and sometimes even in a tactful way to educate him—and not least under present circumstances, when more often than not the customer is a Government Department. The old adage that the customer is always right was certainly not invented by a steelmaker. All these various activities may be included as research; none of them can be excluded with impunity by those responsible for the management of a great modern steelworks."

In recent years, however, he has noticed a growing tendency to distinguish between research into processes and research into products; or, again, between activities which are variously referred to as practical, short-range research or technical development, and activities which are dignified by the title of fundamental, scientific or long-range research. The former are supposed to form the useful occupation of hard-working officials engaged on production and their technical staff; the latter are said to be the sphere of illustrious scientists working in purely academic surroundings. A view with which he profoundly disagrees, and one utterly opposed to the spirit which has invigorated the Iron and Steel Institute from its foundation. Nothing could be further removed from the conception of those great men to whom the iron and steel industry of the world owes so much and whose names are among those inscribed in the list of Bessemer Medallists in the entrance hall of this building—Bessemer himself Lowthian Bell, Siemens, Thomas and Gilchrist and, in more recent, times, Hadfield and Talbot, who is now one of our Senior Past-Presidents. Although Mr. Mannaberg's name is not in this list, Mr. Henderson specially referred to his services to the industry in Lincolnshire and to the country as a whole. He recalled that it was largely due to the initiative of Mr. Mannaberg that the Fuel Department of the British Iron and Steel Federation was set up, which, under the direction of Sir William Larke, has developed into the present-day Technical Department. None of these men drew hard and fast lines between research and practice and between development and operation. Holding this opinion, it is not surprising that Mr. Henderson regards the present set-up of co-operative research in this country by the existing organisations as being transitional.

Mr. Henderson continued: "At present, collective research by the steel industry is carried out by Research Committees responsible to the Iron and Steel Industrial Research Council. A majority of this Council is composed of representatives of the industry and the secretariat is provided by the Federation. It forms part of the organisation set up by the Government through the Department of Scientific and Industrial Research during the last war, and is indebted to that Department not only for generous financial support, but also for the helpful guidance of its representatives.

"The Committees working under the Research Council are known to most of you, and their membership is drawn almost exclusively from members of this Institute. A number of the Committees, especially those dealing with works operations, are serviced by the Technical Department of the Federation, and owe much to the enthusiasm of the Federation's officials. There are also some twenty Committees and Sub-Committees which look to the Institute secretariat for this assistance; these deal with such problems as are of a more fundamental character. But in all cases where useful work is being done, this is largely due to the enthusiasm of the members, who are generally the works officials especially concerned with the problems under investigation, or members of their research staffs. It is this constitution of the Research Committees that forms a unique feature in the collective research activities of the iron and steel industry. No praise can be too high for the enthusiasm and sacrifice of time which members of these Committees have brought to their collective deliberations. Not only is their knowledge put at the unfettered disposal of the problems under consideration, but the results obtained from these deliberations are at once available for use

INDEX TO VOL. 25.

In view of the paper shortage and to avoid waste, it is not proposed to issue an index with the May issue of "Metallurgia." Readers who desire an Index to Vol. 25 are asked to advise us, as copies will be prepared and despatched on request.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

in the works. It should be borne in mind that the industry maintains no large central laboratories for the prosecution of research and that such experiments as the Committees wish to put in hand are carried out either in works and works laboratories or in such collaborating organisations as the National Physical Laboratory and the Technical Universities.

"The division of research roughly into technical and fundamental problems is due, in my opinion, to historical accident rather than to any true functional division. After many years' association with the Research Committees of the Federation and of the Institute, I consider that while the present arrangements may offer certain advantages, there would be much gained by a complete fusion of these parallel activities. The problem deserves, and should receive, the most careful study so that we may continue to encourage the development of invention and technique. We must see to it that the rising generation is fully equipped to carry forward the work begun by the great men of Britain whose names have already been mentioned and who placed our country in the forefront of world progress."

We believe the views expressed by Mr. Henderson, with regard to research in the iron and steel industry, will strike responding chords in the minds of many associated with other industries, and, for this reason, believe they will have a wider appreciation.

Razor Blades for British Steelworkers

JUST as friendly consideration in a personal emergency is admirable and appreciated, so is the tangible expression of good feeling, which has been shown by workers in the United States iron and steel industry to their co-workers in this country by the gift of razor blades. That this gift of approximately 200,000 razor blades struck a responsive chord in the hearts of the British iron and steel industry is indicated by the interesting meeting in London, at which Lady Beatty, on behalf of the "Bundles for Britain" movement, presented the gift, in the form of a token packet, to Mr. James Henderson, President-Elect of the Iron and Steel Institute, for distribution among those engaged in the industry in this country. Lady Beatty was accompanied by Lady Strathallan, and Sir William Larke, Director of the British Iron and Steel Federation, and Mr. T. Chadwick, Chairman of the National Union of Foundry Workers, supported Mr. Henderson.

In making the presentation, Lady Beatty said that these razor blades had been contributed by people engaged in the American iron and steel industry to be sent specially to workers in the same industry in Great Britain. Whole families had helped in the work, even the children assisting the collection of the blades. She added that a further consignment was on the way, which would bring the total number up to about 300,000.

In expressing thanks for the gift, Mr. Henderson prefaced his remarks by saying that the ceremony was taking place in a very appropriate venue, for the building now occupied by the Iron and Steel Institute had for many years housed the American Embassy—we were thus on what at one time had been American soil. To give such a typically steel product as razor blades to our steelworkers, continued Mr. Henderson, was a most happy thought. The men will appreciate the deep sincerity and kindly feeling behind the gift; moreover, speaking as an expert on the subject, he thought it was revealing no improper secrets if he said that razor blades had of late been rather scarce, owing possibly to the fact that our supplies of cold-rolled steel had, for some time past, been devoted to other more warlike purposes than the daily tussle between man and his beard.

In offering thanks to the many who had contributed and had helped in collecting and forwarding the blades, Mr. Henderson specially mentioned the names of Mr. Joseph J. Hannigan, Executive Secretary of Razor Blades for Britain and the American Iron and Steel Institute. He added that in many cases the addresses of donors were attached to the packages of blades, and it is very likely that recipients will express their thanks personally.

Sir William Larke and Mr. Chadwick associated their respective organisations with the Iron and Steel Institute in warmly thanking the donors for the thoughtfulness and the spirit of friendliness which animated the gift. This gesture of our American friends could be regarded as an indication that the comradeship in arms of to-day will develop into a lasting friendship in days of peace.

The Institute of Physics

SOMETHING of the important part physics is playing in the war effort was disclosed at the recent conference on "X-ray Analyses in Industry," held in Cambridge by the Institute of Physics. The discussions on the first day were concerned with technique, and provided an opportunity for those employing X-ray analysis to exchange some of their experiences. The second day's discussions were devoted to industrial applications, and representatives from the chemical, steel, light alloy, engineering and other industries told of novel applications of these new methods of examination. Not only are they being employed for the solution of urgent day-to-day problems, but are also utilised for the study of fundamental problems arising in the war industries. It seems that the physicist may be able to make a useful contribution to the interpretation of the peculiar behaviour of metals when strained, which is the immediate concern of the armament and shipbuilding industries.

Professor Sir Lawrence Bragg, the President of the Institute, enthralled the 300 Conference members with his evening discourse on "The History and Development of X-ray Analysis," in which he recounted how he and his father, the late Sir William Bragg, studied the diffraction of X-rays by crystals and pioneered the subject until it is now almost a separate branch of science. Some interesting photographs and apparatus demonstrating recent developments were exhibited in the Cavendish Laboratory by members attending the Conference.

Institute of British Foundrymen

THE thirty-ninth annual general meeting of the above Institute will be held at the Waldorf Hotel, Aldwych, W.C. 2, on June 20, 1942. After the normal business meetings the following technical papers will be presented for discussion:

"The Production of Uniform Steel for a Light Castings Foundry," by C. H. Kain and L. W. Sanders.

"Pearlitic Malleable Cast Iron," by Carl F. Joseph (American Foundrymen's Association Exchange Paper).

'The Substituting of High Duty Grey Iron for Steel Castings,' by J. Blakiston.

Non-ferrous Papers on low-tin and tin-free bronzes will also be presented.

The Edward Williams' Lecture on "Foundry Teamwork," by Dr. H. W. Gillett (Chief Technical Adviser, Battelle Memorial Institute, Columbus, Ohio, U.S.A.) will be presented in full on behalf of the author by Dr. C. H. Desch, F.R.S.

The meeting commences at 10-30 a.m., and arrangements are being made for luncheon at 1 p.m., and those desiring to attend should communicate with Mr. J. Bolton, Acting Secretary, St. John Chambers, Deansgate, Manchester, 3, without delay.

E. J. FOX GOLD MEDAL

The Council of the Institute has accepted the recommendation of the assessors (Sir William Larke, K.B.E., and Dr. J. E. Hurst, J.P.) that the 1942 award of the E. J. Fox Gold Medal be made to Mr. P. H. Wilson, Assistant Managing Director (Technical) of the Stanton Ironworks Co., Ltd. The award is made in recognition of Mr. Wilson's work in the development of the centrifugal casting process for the production of cast-iron pipes.

The Iron and Steel Institute

The Seventy-Third Annual Meeting held in London

THE Seventy-Third Annual Meeting of the above Institute was held at the official Offices, on May 7, 1942, and although war conditions curtailed the duration of the meeting and interfered with the social activities generally associated with this occasion, there was sufficient indication that adjustments made due to present conditions have in no way interfered with the major activities of the Institute.

The President, Mr. John Craig, C.B.E., D.L., occupied the chair, and after the minutes of the previous meeting had been taken as read, he offered a very cordial welcome to the Institute's guests and visitors from other countries. A special welcome was offered to Dr. G. B. Waterhouse, from Washington. Mr. Craig said that the fact Dr. Waterhouse reached Washington via Sheffield was perhaps an added quality, even for an American! A welcome was also accorded to friends from Poland, who had been at previous meetings, and to a visitor from China, Dr. H. Lee. With members present from Great Britain, the United States of America, Poland and China, the gathering was certainly representative.

The next duty of the President was a sad one, and feeling reference was made to the loss the Institute has sustained by the death of some of its members. Special reference was made to the death of Sir William Bragg, whose relationship with the Institute was always cordial; at all times he was willing to help in its work, and his passing is a great loss. Mention was also made of the death of Mr. Percival Smith, who took a very prominent part in the work of the Institute and served it ungrudgingly, and with great loyalty and enthusiasm. The meeting stood in silence for a few moments in memory of these and others.

Award of the Bessemer Gold Medal

The President expressed his great pleasure in stating that the Council unanimously decided to award the Bessemer Gold Medal for 1942 to Mr. Eugene Gifford Grace, Eng.D., of the Bethlehem Steel Corporation, U.S.A. That the decision of the Council would meet the unanimous approval of all the members he had no doubt, for all recognised the great services which Mr. Grace has rendered to the industry, not only in America, but in its world-wide aspect, and his very friendly co-operation with the industry in this country. The Medal will be handed to Mr. Grace officially at a meeting of the American Iron and Steel Institute in the United States at an early date.

Honorary Members

At the last Autumn Meeting, it was announced that Mr. Walter S. Tower, President of the American Iron and Steel Institute, had been invited to accept honorary membership of the Institute. The President announced that Mr. Tower has accepted with great cordiality and has expressed himself as feeling very highly honoured by the invitation. It is particularly noteworthy that the Council have unanimously agreed to invite Mr. Harry Brearley, of Sheffield, a Bessemer Medallist, to become an honorary member of the Institute. In announcing this invitation, the President said he was sure that the decision would give all pleasure; we recognise his great ability, and many of us have read his delightful books.

Report of Council and Statement of Accounts

The Secretary (Mr. K. Headlam-Morley), at the invitation of the President, gave a brief summary of the Annual Report. When dealing with joint meetings of local societies, he mentioned that the Council had instructed him to express the hope that it would be possible for more meetings of this character to be held in the future.

The Hon. Treasurer (Mr. James Henderson) presented the accounts. Dealing first with the general fund, the year's operations resulted in an excess of expenditure over income of roughly £752, mainly due to the outbreak of war with Japan. With regard to the Trust Funds, the income of the Andrew Carnegie Research Fund exceeded the expenditure by £942. Mr. Henderson called attention to the fact that the Institute is not receiving a reasonable number of applications for scholarships in connection with this fund. It may be it is not sufficiently widely known that this fund exists for the purpose of assisting research, and that grants usually of the order of £100 in a year are given for suitable original research.

The deficit on the year's working is rather exceptional; usually there is a slight surplus of income over expenditure. It is not, of course, the purpose of the Institute to build up a big reserve, but rather to see that as much money as possible, which becomes available for the Institute's work, is wisely spent. In concluding, Mr. Henderson said: "This is the last occasion on which I shall have the privilege of addressing you as Treasurer; as from this meeting, that office passes to Mr. Richard Lyttelton, who will bring a new mind and fresh blood to the question of finance. Before laying down this office, I want to thank Mr. Headlam-Morley for his help in supervising the finances of the Institute. He has made the task exceedingly pleasant, and easy to carry out. I would also like to thank Miss Dowd for her consistent care in handling the accounts."

Vice-Presidents and Members of Council

No other members having been nominated up to one month previous to the present meeting, the retiring Vice-Presidents and Members of Council were presented for election and agreed to. They are:—

Vice-Presidents: Dr. C. H. Desch, F.R.S.; Dr. W. H. Hatfield, F.R.S., and Sir William Larke, K.B.E.

Members of Council: Mr. W. J. Brooke, Mr. E. J. Fox, Mr. J. Sinclair Kerr, Dr. T. Swinden, and Mr. A. B. Winder.

Induction of President-Elect, Mr. James Henderson

Mr. John Craig, the retiring President, said: "I now come to the final duty I am called upon to discharge. I have great pleasure in asking Mr. James Henderson, the President-Elect, to take the chair. He comes to this high office—the highest office on the technical side of the industry which the Institute can offer to anyone—fully qualified by experience, by knowledge, and by loyalty to the Institute to occupy this position. We trust that he will be the President who will welcome peace to this country and to our industry. We look forward with great hope to his period of office, and we wish him well."

After taking over the chair, the President expressed his appreciation of the honour conferred upon him. "It is impossible," he said, "for me adequately to express my gratitude to you, but I hope that, when the time comes for me to lay down this office, I shall be able to feel that my time in your service has not been entirely mis-spent. This is one of the few occasions on which I regret that I cannot put the clock back and be five or ten years younger. If I follow in the footsteps of my predecessor, Mr. John Craig, I shall not go far wrong."

Presidential Address

In view of his long association with the British iron and steel industry as practised in North Lincolnshire, Mr. Henderson was able to record a useful report on the importance of that district in the country's national economy. He is the first President of the Institute who has been directly connected with that part of the country. His remarks were of a general character, but he gave a

very useful bibliography from which those who wish will obtain full technical details. In the concluding part of his address he discussed the research activities of the industry, with the growth of which he has had many contacts. Here, it is only possible to present Mr. Henderson's address in a substantially abridged form.

The iron and steel industry of North Lincolnshire is based on the deposit of ironstone known as the Frodingham bed. The deposit must have been known many centuries ago, as traces of primitive workings by the Romans are found, but it was not until the middle of the last century that operations on a commercial scale were undertaken. The first blast furnace was started up in 1862 at the Trent Iron Works. In the following twelve years other furnaces were built, all being of a simple character with the modest equipment of those times. The latest examples of that period were built in 1874 by the Appleby Iron Co., Ltd., which had a capital of £50,000 for a four-furnace plant.

All of these furnaces made forge and foundry iron for sale, and, while handsome profits were sometimes realised, the financial returns were unsatisfactory as a general rule. Much credit is due to Messrs. Cliff, the owners of the Frodingham Iron Co., in that they decided in the year 1888 to put down a steelmaking plant. They consulted Mr. Percy Gilchrist, who advised them to adopt the basic open-hearth process, then in its experimental stages. He secured for them the services of Mr. M. Mannaberg, and steelmaking actually began at the works of the Frodingham Iron and Steel Co., Ltd., in 1890. Mr. Mannaberg had all the qualities of a pioneer—enterprise, energy and confidence: and it is without question due to him in the first place that the district has grown to its present importance. In 1912 the Frodingham Company, in association with the Steel Company of Scotland, Ltd., bought the Appleby Iron Co., Ltd., to form the basis of a new steelmaking plant: and in 1917 the United Steel Companies, Ltd., acquired both the Frodingham and the Appleby Companies. These two were later merged to form the present Appleby-Frodingham Steel Co., Ltd. The Frodingham Works are equipped for the manufacture of sections, joists and such like, and the Appleby Works for plates.

In 1912 Messrs. John Lysaght, Ltd., set to work a completely new and well-planned plant for the manufacture of coke, pig iron and steel, with mills for rolling sheet bars and billets. Originally of ordinary qualities, these are now made in highly specialised and alloy grades. Fuel economy has been brought to a very high point of efficiency.

About 1916 the blast-furnace plant of the Redbourn Hill Coal and Iron Co., Ltd., which was one of the early plants, was acquired by Messrs. Richard Thomas and Co., Ltd., who erected coke-ovens, steel furnaces and rolling mills for billets, sheet and tinplate bars. In 1938 large reconstructions and extensions were made, effecting a greatly increased production and efficiency. A subsidiary company, the Whitehead-Thomas Bar and Strip Co., Ltd., have a modern bar mill.

As already stated, the Frodingham ore bed is the foundation of the district's industry, and its characteristics deserve some attention. It is now being worked in open quarries, but in a few years an increasing proportion of the requirements must be got from underground. It is a definitely low-grade ore, the average content of iron being under 23%. It is probably the leanest ore in the world being successfully smelted. As a whole, it contains an excess of lime over silica, and a silicious ore must be brought in to secure a fluxing mixture. Ore from the Northamptonshire bed is commonly used. While the local ore is cheaply won by modern methods and machinery, its variable composition has presented through the whole history of the district very serious technical problems. To appreciate this difficulty the following figures are helpful: A vertical cut can have layers of ore varying from 14% to 26% of iron, 4% to 25% of silica, and 4% to 35% of lime (CaO). Also two places in a quarry face, say, 1,000 yds. apart, can have average analyses of vertical cuts varying between 18 and 24% of iron, 4 and 7% of silica and 20 and 27% of lime. In general, the mines management and the blast-furnace control are in continuous contact, affording all possible advance information of the character of the supplies coming forward from time to time. Excellent results have been obtained in this way, but there has been a constant striving for more reliable and error-proof methods. Very successful results have been achieved in recent years at the South Works of the Appleby-Frodingham Co. Extensive and costly plant has been erected, in which the ore as it comes from the quarries is crushed in two operations to a size not over 2½ in. Screening takes place at various stages, and the fines go to form part of a sinter mixture. Northamptonshire ore is crushed, dried and screened, the fines again going to the sinter plant, where a mixture of all fines, along with the blast-furnace flue dust and coke screenings, is sintered in a Dwight-Lloyd plant to form a product of reasonable regularity and mechanical condition.

The larger sizes of the ores coming from the crushing plant are taken to a "bedding" plant, where layer after layer is spread horizontally on a prepared floor and built up in an elongated pyramidal heap to a convenient height. The mixture is removed by vertical cuts and conveyed by belt to the blast-furnace bins. The resulting product is regular in composition to a surprising degree. This plant is unique in the world as applied to blast-furnace practice.

The effect of this ore preparation is remarkable in obtaining increased output from the furnace and lower coke consumption. Coke used averages about 21½ cwt. per ton of pig iron in the newest large furnaces with an ore mixture of about 68 cwt. per ton (no limestone is required for reasons previously explained). Other furnaces in the district operating without these facilities consume 26 cwt. to 30 cwt. of coke per ton of iron.

The district owes its existence to low-cost pig iron, based on local ores having at present a unit of iron value of about 2·3d. per ton, Northamptonshire ore 3d. per ton-unit, and a reasonably priced coke obtained either in the district or from coke-ovens on the coal fields which are 30 to 50 miles distant. These advantages, combined with excellent furnace practice, result in pig iron which has one of the world's lowest costs.

While these advances in blast-furnace technique have been taking place, great improvements in open-hearth steelmaking have also been made. Generally, furnaces are heated by a mixture of blast-furnace and coke-oven gases. All the works employ fixed or tilting furnaces fed with liquid metal, some with only such scrap as is produced within the works: others supplement this with moderate amounts from outside. Furnaces vary considerably in size and type, but the Appleby-Frodingham Co. have developed as standard practice tilting furnaces of 250 to 300 tons capacity, working a process based on the Talbot continuous method. Outputs average 1,800 to 2,000 tons per week, with a high thermal efficiency.

Progress at the Lincolnshire works would not have been possible without research. Research in a steel company is not an end in itself. It should not be directed to the increase of knowledge merely for the sake of increasing knowledge: it should rather be directed by the practical desire to improve the quality of the product and profitably to modify the processes of manufacture—as an example, to make as cheaply as possible a steel ingot or bar suitable for the purpose intended and of improved functional quality. This conception does not limit the field open to research workers employed in the iron and steel industry: it merely sets a goal to their endeavours. There is open to them, indeed, a virtually limitless field of activity, and naturally they should be qualified to derive assistance from the latest developments of science.

Technical Session

A vote of thanks to the President for his address was proposed by Sir William J. Larke and seconded by Dr. W. H. Hatfield, and was carried with acclamation, after

which some technical papers were presented for discussion. Although the time available was short, useful and interesting discussions took place on "The Temperature Distribution in the Liquid Steel in Various Steelmaking Processes," and on the paper dealing with "The Work-Hardening and Ageing of Steel." The papers presented are reviewed in the following notes.

The Temperature Distribution in the Liquid Steel in Various Steelmaking Furnaces*

By D. A. OLIVER, M.Sc., F.Inst.P., and T. LAND, M.A.

PUBLISHED literature on the physical chemistry of steel-making processes is very vague on the actual temperatures attained, until the advent of the Fitterer[1] and the Schofield-Grace[2] types of thermo-electric immersion pyrometer. Five years ago measurements at isolated points in a bath of liquid steel were somewhat precarious achievements of a research character, and it took many months before the real potentialities of the Schofield-Grace technique were realised for routine measurements of liquid steel temperature. The object of the present paper, submitted by the Liquid Steel Temperature Sub-Committee, is to extend the study of the subject to include data on the temperature distribution in various types and sizes of steel-making furnaces.

Only certain types and sizes of furnaces were available, and observations had to be taken with a minimum dislocation of production. The initial object was to obtain observations on a wide range of furnaces under as many different conditions as possible. Surveys have been made of a 40-ton Siemens' acid open-hearth furnace; a 25-ton Siemens' acid open-hearth furnace; a 12-ton electric arc furnace of the 3-electrode Héroult type; a 3-ton and a 30-cwt. electric arc furnaces of the 2-electrode, bottom-return type; and a 100-lb. high-frequency furnace.

It was not possible to explore all the furnaces with equal thoroughness, but sufficient information has been obtained to draw useful conclusions and guide future work. No surveys have been made of basic open-hearth furnaces.

The Schofield-Grace quick-immersion technique of liquid steel temperature measurement, which is in operation as a routine control on all furnaces surveyed, was used throughout the present investigation. Whenever possible, observations were taken at a uniform depth at points distributed over one-half of the bath, and at different depths at one or more points in the bath. The temperatures were measured at stages in the steel-making process likely to yield extreme results or at times considered to be significant for the purposes of control. For easy reference, the results of the surveys in the open-hearth and arc furnaces are summarised in a Table.

Open-Hearth Furnaces

It will be seen from Table I (*a*) that while the bath was on the boil the stirring action of the evolved gases maintained a remarkable degree of uniformity of temperature. This uniformity persisted even when the rate of oxidation of the carbon had been reduced to a low value at the going-on stage. After the addition of deoxidising agents, the temperature of the bath became considerably less uniform, and variations up to 20° C. were observed. However, the value of the temperature measured at the standard position used for routine control never differed by more than 6° C. from the unweighted mean of all the temperature measurements in that survey. The general tendency of the results is to show rather higher temperatures towards the edges of the bath than at the centre.

Electric Arc Furnaces

Furnaces of the electric arc type (*b*) have been surveyed in particular detail, and the results are of considerable interest. As in the case of the acid open-hearth furnace, the temperature while the bath is on the boil is remarkably uniform. When the finished slag had been added the bath began to build-up temperature differences. The variation from point to point at a constant depth seemed to be very small. Large differences, however, were found in the vertical direction. The observations in each survey were taken after rabbling the bath, and the rather different results reflect a variation in the effectiveness of the mixing. It seems clear that, under the conditions of operation encountered, the top 12 in. of the metal normally vary in temperature by about 15° C. Below this depth there is frequently a cool layer which is not always greatly disturbed by the process of rabbling. The metal within 2 in. to 3 in. of the bottom of the bath has occasionally been found to be 50° or even 70° C. below the temperature of the hot metal above it.

A rough calculation shows that, for the size of the furnace at present under consideration, the uniform temperature layer comprises about three-quarters of the metal in the furnace. The average temperature of the remaining cooler metal may be 20° or even 30° C. below that of the upper portion. A temperature test taken at a depth of 6 in. below the surface should, however, give the average temperature of the whole bath with an error of not more than 10° C.

The small size of the other arc furnaces investigated enabled a much more thorough mixing to be achieved, and variations in temperature rarely exceeded 10° C. The same general trends are observed as in the larger furnaces.

High-Frequency Furnace

The metal in the high-frequency furnace undergoes very violent agitation when the heating current is passing through the coil. However, temperature measurements are frequently made with the heating current switched off, and it was thought advisable to investigate the uniformity of temperature under these conditions. The temperature was investigated in a small 100-lb. high-frequency furnace, having an internal diameter of 7 in. The radial thickness of the lining of rammed magnesite was 1 in. The steel filled the furnace to a depth of 10 in. Successive measurements were made at the top, middle and bottom of the furnace, and then at each position again, over a period of a minute. The temperature at the bottom of the furnace initially falls much more quickly than at other positions, but later there is a slower cooling rate at the bottom and the temperature then falls more rapidly at the centre and near the top.

It would appear that the temperature determination made at a depth of 4 in. is likely to differ from the true mean temperature by less than 10° C.

Conclusion

The observations show that during the period when the bath is on the boil the temperature is very uniform. This uniformity persists in the acid open-hearth furnace even when the activity of the bath is quite low and the bath is approaching equilibrium at the going-on stage. The degree of uniformity will depend upon the activity of the bath, and during the boiling period will vary between ± 2° and ± 5° C. When the bath is killed and quiescent, greater temperature gradients begin to build up. The vertical gradient appears to be about 10° C. per ft. in the acid open-hearth furnaces, and the maximum horizontal variation at a constant depth is about 15° C. The horizontal variation seems to be less regular and may in part be due to the distribution of cold additions and to the form of the gas flame. In the basic electric arc furnaces the vertical gradient tends to become considerably greater than in acid open-hearth furnaces, and is only kept within reasonable limits by frequent rabbling. The usual degree of rabbling keeps the gradient down to about 10° C. per ft. in the upper layers, although temperature differences of more than 50° C. may be encountered near the furnace bottom. If, therefore, a suitable place is chosen for taking a single observation of the temperature of the liquid steel, it can be deduced that the result obtained will not greatly differ by more than

* Paper No. 10/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Liquid Steel Temperature Sub-Committee).

1 G. R. Fitterer. *Iron Age*, 1937, vol. 140, July 22, p. 38.

2 F. H. Schofield and A. Grace. Second Report of the Liquid Steel Temperature Sub-Committee (Eighth Report on the Heterogeneity of Steel Ingots), *Iron and Steel Institute*, 1939, *Special Report* No. 25, p. 239.

10°–15° C. from the true average temperature of the bath. On the instrumental side, owing to thermocouple effects and the unavoidable errors of observation, there is a further possible error of ± 5° C. The final absolute uncertainty may thus approach ± 20° C., but in most normal cases the error is likely to be of the order of ± 10° C. This degree of accuracy is considered quite satisfactory for the large majority of cases, although there may be occasions when it will be advisable to make several measurements at two or more locations in the bath.

The Work-Hardening and Ageing of Steel

By Professor J. H. ANDREW, D.Sc., and H. LEE, Ph.D., B.Eng.

THIS paper deals with experimental work undertaken with a view to proving or disproving the hypothesis, formulated by Professor Andrew[1] in 1938, that the cold-working of iron and steel gives rise to the formation of the γ phase. This theory was based on published data, and it was realised that, before it could be accepted by the metallurgical community, further experimental work was essential. It was thought that the methods of attack favoured by the metallurgist might usefully be employed, and if the results obtained were promising, X-ray examination could be brought to bear on the problem at a later date.

Experiments have shown that the properties of cold-worked steel are similar in many respects to those of a steel of the same composition in the quench-hardened condition. Both quenching and cold-working produce an increase in hardness, maximum stress and electrical resistance. In a high-carbon steel, cold-drawing will produce a much higher maximum stress than can be obtained by the most drastic quenching. The fact that an increase in carbon content up to a certain optimum figure results in a proportionate increase in maximum stress, which may attain a value of over 200 tons per sq. in. for a particular degree of drawing reduction, leads to the definite conclusion that carbon must play an important part in this increase, and the only possible conclusion is that carbon must be taken into solution during the cold-working process.

The solubility of carbon in α-iron is known to be low; therefore, it is a necessary corollary that γ-iron must form during cold-working. Whether the final density of the material be reduced or increased as the result of cold-working, at the point in the die or the rolls where the maximum reduction is effected compressive forces must momentarily come into play. According to the theory of Le Chatelier, a compressive force will assist in the formation of a denser phase, which in this particular case would be γ-iron. Further, the heat generated along the planes of slip can quite conceivably be sufficient to raise instantaneously the temperature locally to a sufficient degree, not only to promote the α–γ change, but also to bring about the solution of carbon. The two effects, due to pressure and increase in temperature, will therefore combine to bring about this transformation. The amount of experimental evidence in favour of this hypothesis is considerable. The transformations recorded by thermal and dilatation curves on heating quenched or cold-worked steels present several points of similarity, namely, (*a*) a transformation usually associated with the decomposition of martensite, (*b*) a transformation in the neighbourhood of 150° C., (*c*) a thermal evolution over a range of temperature between 400° and 600° C. associated with recrystallisation and with the decomposition of austenite, and (*d*) the simultaneous absorption and evolution of heat between 100° and 125° C., which disappears on ageing.

The most convincing proof of the formation of austenite on cold-working is perhaps the property of secondary hardening on tempering and the expansion in the neighbourhood of 100°–150° C. It is difficult to imagine any reaction other than the α–γ transformation that could effect such an expansion. The development of austenite or martensite bands by means of a sharp blow is convincing evidence, since martensite can only be formed by the decomposition of austenite. Micrographs shown by the authors, and others recently published by Trent, leave no doubt as to the validity of this argument.

The phenomena of quench-ageing and strain-ageing have been dealt with very fully, and experimental data would seem to show that the much greater increment in hardness resulting from quench-ageing, as compared with strain-ageing, is due to an actual formation of Fe_3C in single molecules, without its precipitation, and therefore without the formation of a less dispersed state. The strain in the lattice brought about by this labile state is, it is suggested, the cause of the marked increase in strength and hardness. In a cold-worked steel or in one that has been quenched from about Ac_2, it is reasonable to assume that sufficient nuclei of free Fe_3C would be present to bring about a precipitation immediately following its formation, and, whereas this disperse precipitation would increase the hardness by interference with slip, the effect produced would not be as great as that of the non-associated molecules holding the iron lattice in a stressed condition. It would appear that ageing occurs in all cold-worked and quenched steels to some extent, but, as only the ferrite is affected, when the amount of this constituent decreases and at the same time the normal hardness increases owing to the greater carbon content, the total effect of ageing becomes less.

Tempering at 200°–350° C. after cold-working cannot be regarded as an ageing treatment, for in a carbon steel the greater part of the carbide is deposited and coalesced within this temperature range. Such a treatment is essentially associated with secondary hardening. Mechanical tests undertaken to determine the relation between grain-size and mechanical properties have shown for the particular low-carbon steel employed that, below a certain minimum grain-size, curves depicting the relationships between grain-size and property become asymptotic.

Certain interesting relationships have been found. For instance, if the elongation at the point of maximum stress is measured before necking has taken place, the value is constant for all sizes of grains. This feature must be of some significance, but it is difficult to explain; it may be that the total length of movement on all the slip planes added together is constant—that is to say, the fewer the slip planes, the greater the distance of glide on these planes. When the crystal size is small, a greater load is necessary to produce the same elongation, owing to the increased angularity of the glide planes.

It was also found that the maximum stress bore a linear relation to the length of the yield. This is of particular interest, for it leads to the conclusion that the changes undergone during yield are responsible for the maximum stress attained. This particular section of the investigation led the authors to a new theory of the yield. In a body-centred metal, such as molybdenum, the load-extension curve is similar to that of a low-carbon steel with respect to the elastic portion and the yield, the difference being that fracture occurs after stretching has taken place at a constant load which corresponds to the yield-point in steel. The so-called "plastic" part of the curve is absent. Molybdenum undergoes no allotropic transformation, and it is suggested that this difference in the form of the curve is due to the fact that iron and steel in the body-centred form begin to extend at a certain load—i.e., the yield—and when this extension takes place γ-iron begins to form on the slip planes, but undergoes almost simultaneous partial transformation to the α-form. The result is the formation of crystals of α-iron at the glide planes, with the resultant strengthening of the whole. When slip on the planes of easy glide is completed or stopped by this formation of small crystals, further extension can only be brought about by the more difficult glide planes coming into action. As this phase of the test would be associated with considerable crystal rotation, the formation of these layers of small

1 Andrew. *Journal of the West of Scotland Iron and Steel Institute*, 1938, vol.46, p. 51.

crystals would increase more rapidly, and their inclination one to another would also add to the strength of the materials under test. If carbon were present, it would, by going into solution, add a further increment to the load necessary for continued extension until rupture finally occurred. At the point of rupture, where the final reduction in cross-sectional area is so marked, there are indications that there is a perceptible formation of the face-centred form, and that final fracture occurs in the planes of a face-centred lattice. There is evidence to show that, even after stressing to the yield and removing the load, a small amount of iron is retained in the γ-state, a dilatation curve of a specimen stretched to the yield showing a definite low-temperature expansion on cooling after reheating to 200°–350° C. This effect was considerably greater when the specimen was loaded to the maximum stress.

Further proof of this contention was afforded by the determination of the magnetic permeability of a tensile test-piece during the mechanical test; during the yield there was a virtual rise in permeability. That this was due to the formation of non-magnetic films, such as austenite, along the cleavage planes is supported by the work of Wall,[2] who showed that the coating of iron wires with a non-magnetic metal gave a considerable increase in permeability.

The application of these theories to the results obtained with mechanical tests gives rise to the obvious conclusions that the breaking stress of any steel depends largely upon the reactions which are taking place within the plastic portion of the load-extension curve. The total elongation undergone during test and the degree of dispersion of the carbides in the original test-piece are essential factors leading to the final result, which is dependent upon the formation and retention of austenite and its decomposition product, martensite, during test.

In conclusion, it may be stated that all data obtained have shown that the chief factor involved in cold-working, whether cold-rolling, wire-drawing, cold-pressing or mechanical testing, lies in the formation during these processes of austenite.

First Report of the Standard Methods of Analysis Sub-Committee of the Committee on the Heterogeneity of Steel Ingots*

IN view of strong opinions expressed regarding the accuracy of existing methods of analysis, upon the results of which casts of steel were liable to rejection, particularly when made in acid-lined open-hearth furnaces, the Committee on the Heterogeneity of Steel Ingots decided to form the Standard Methods of Analysis Sub-Committee. The first work of this Sub-Committee was directed to the standardisation of methods for the determination of sulphur and phosphorus in carbon steels, and this Report deals with recommended methods which have been devised from both theoretical considerations and practical experiments. The recommended method for sulphur is a refinement of the gravimetric *aqua-regia* barium-sulphate process, and for the determination of phosphorus is recommended a modified bromide process, whereby arsenic is eliminated prior to the precipitation of the phosphorus as the yellow precipitate, in view of the fact that practically all commercial steels contain arsenic.

It is emphasised that the methods recommended were devised primarily for "referee" purposes, and, therefore, little cognisance was taken of the time or expense involved in the determination of either element. The main object was to devise standardised processes yielding comparable results when carried out by different chemists using the same samples of steel. Precise details regarding analytical procedure are given below.

* Paper No. 11/1942 of the Committee on the Heterogeneity of Steel Ingots (submitted by the Standard Methods of Analysis Sub-Committee).

2 Wall. *Nature*, 1937, vol. 139, p. 928; 1938, vol. 141, p. 1016.

Aqua-Regia Gravimetric Method for the Determination of Sulphur in Carbon Steels

Solutions Required.—Dilute hydrochloric acid: Dilute 5 ml. of hydrochloric acid (sp. gr. 1·16) to 100 ml. with distilled water. Barium chloride solution: Dissolve 20 g. of barium-chloride crystals in 100 ml. of distilled water.

Procedure.—Weigh 5 g. of sample, transfer to a covered 600-ml. squat-type beaker and add 0·1 g. A.R. potassium-nitrate crystals. Mix 35 ml. of nitric acid (sp. gr. 1·42) with 25 ml. of hydrochloric acid (sp. gr. 1·16) and, immediately after mixing, cautiously add to the contents of the beaker. When the early violent action subsides place the beaker on the hot-plate, digest until solution is complete and evaporate, taking care to avoid spurting.

When the solution is low in bulk move to a cooler part of the hot-plate and remove the cover-glass. During evaporation turn the beaker through an angle of about 90° at regular intervals, in order that the condensed acid on the cooler side may counteract any tendency towards creeping up the walls of the beaker. In this way the solidified mass is concentrated on the bottom of the containing vessel. Slowly move the beaker towards the hottest part of the plate and bake until no smell of acid fumes can be detected. This baking takes about half-an-hour at a temperature of approximately 300° C. Remove the beaker from the hot-plate and cool on an asbestos pad or mat. Add 40 ml. of hydrochloric acid (sp. gr. 1·16), replace the cover and digest at a temperature just short of boiling until all the iron salts are redissolved.

After complete solution evaporate strongly to remove most of the excess acid, and then more cautiously until a scum appears on the surface. Allow to cool slightly and add 20 ml. of hydrochloric acid (sp. gr. 1·10), heating gently until a clear dark-brown solution is obtained. Dilute with hot water to 45 ml. and filter immediately through an ashless paper-pulp pad into a 250-ml. conical beaker. Carefully wash the beaker and filter with cold water and dilute hydrochloric-acid solution alternately until the total volume of the filtrate is about 100 ml. Add 10 ml. of barium-chloride solution, swirl or stir the contents of the beaker and stand over-night or for several hours.

Filter through a tightly-packed ashless paper-pulp pad, washing the precipitate from the beaker with a jet of cold dilute hydrochloric-acid solution containing 1 g. of barium chloride per litre. Wash until the filter is free from iron salts, and continue washing with cold water until chlorides are removed. Remove surplus water by suction and transfer the pad and precipitate to a platinum or porcelain crucible. Dry the filter pad completely at a low temperature (the mouth of the muffle furnace) until the paper chars and gently burns; finally, ignite completely to a temperature between 800° and 900° C. Transfer the crucible to a desiccator, cool, brush the precipitate on to the balance scoop and weigh as barium sulphate, $BaSO_4$.

The sulphur percentage in the steel is calculated thus:—

$$\left\{\begin{matrix}\text{(Weight of } B_aSO_4 - \text{Weight}\\ \text{of "blank")}\end{matrix}\right\} \times \frac{13{\cdot}74}{5} = \text{Sulphur\% in the steel.}$$

Determination of the "blank."—The reagents employed are always liable to contain small amounts of sulphur, so that a corrective blank determination is necessary.

This is conducted side by side with, and in a similar manner to, the steel determination, but without 5 g. of steel drillings, the weight of B_aSO_4 thus obtained being the blank.

Notes.—1. It is recommended that hitherto unused glassware, including reagent bottles and measuring cylinders, be reserved exclusively for the determination of sulphur in steel by the above method.

2. A stock of hydrochloric and nitric acids should also be similarly reserved. It is important that the stock bottles and reagent bottles be stored away from the laboratory atmosphere, in order that contamination of

necks and stoppers by laboratory fumes be avoided unless specially designed bottles be used.

3. The results obtained by the gravimetric *aqua-regia* method must not be regarded as of greater accuracy than ± 0·0015%.

4. When using coal-gas for heating hot-plates, contamination may result from the sulphur dioxide present in the products of combustion of the gas. This may be obviated by providing an adequate skirt in front of the plate so that the products of combustion pass from the back into the flue of the fume chamber. A good draught in the flue is essential in such circumstances.

5. With steels of exceptionally low sulphur contents, such as those produced by the basic electric furnace process, precipitation of the barium sulphate may be accelerated by the addition of a known amount of potassium-sulphate solution of accurately determined strength prior to the barium-chloride addition. The amount added should be equivalent to approximately 10 mg. of barium sulphate.

Determination of Phosphorus

Solutions Required.—Dilute hydrochloric acid: Dilute 5 ml. of hydrochloric acid (sp. gr. 1·16) to 100 ml. with distilled water.

Microcosmic salt solution: Dissolve 2 g. of microcosmic-salt crystals in 100 ml. of distilled water.

Molybdate reagent: Make a suspension of 100 g. of molydic acid in 240 ml. of distilled water. Complete solution of the acid by the addition of 170 ml. of ammonium hydroxide (sp. gr. 0·880). Pour the solution, with repeated shaking, into 1,250 ml. of nitric acid (sp. gr. 1·20) containing 2 ml. of microcosmic salt solution. Stand, and filter immediately before use.

Dilute nitric acid: Dilute 2 ml. of nitric acid (sp. gr. 1·42) to 100 ml. with distilled water.

Dilute ammonium hydroxide: Dilute 1 part by volume of ammonium hydroxide (sp. gr. 0·880) with 2 parts by volume of distilled water.

Ammonium acetate solution: Dilute 1 part by volume of glacial acetic acid with 2 parts by volume of distilled water and neutralise by the addition of ammonium hydroxide (sp. gr. 0·880). Just acidify by the addition of acetic acid.

Ammonium-chloride solution: Dissolve 25 g. of ammonium-chloride crystals in 100 ml. of distilled water.

Lead acetate solution: Dissolve 4 g. of lead-acetate crystals in 100 ml. of distilled water.

Procedure.—Cover 2 g. of sample in a 400-ml. conical beaker with 25 ml. of nitric acid (sp. gr. 1·42) and add cautiously 15 ml. of hydrochloric acid (sp. gr. 1·16) at such a rate that the liquid, when frothing, does not overflow. Digest until dissolved, evaporate to dryness and bake at a temperature of about 300° C. for 20 mins. Cool, take up with 40 ml. of hydrochloric acid (sp. gr. 1·16) and boil until a clear solution is obtained.

Add 20 ml. of distilled water and filter through a paper-pulp pad into a 400-ml. conical beaker, washing with dilute hydrochloric acid and keeping the bulk as low as possible. Add 5 g. of ammonium bromide and, with the cover of the beaker removed, evaporate until white fumes appear and the volume is reduced to about 4 ml.

Add 10 ml. of nitric acid (sp. gr. 1·42) and warm gently until the bromine is eliminated. Dilute with 40 ml. of cold distilled water and add ammonium hydroxide (sp. gr. 0·880) in slight excess (about 8 ml. are required). Just re-dissolve the precipitated ferric hydroxide by the cautious addition of 4—5 ml. of nitric acid (sp. gr. 1·42) and add 4 ml. in excess. Adjust the temperature of the solution to 80° C., add 35 ml. of filtered molybdate reagent, shake the solution until the precipitate forms and allow to stand for 20 mins.

Filter the yellow precipitate on an ashless paper-pulp pad, washing with cold dilute nitric acid until the washings are free from iron salts (usually about six washes suffice). transfer the funnel and filter to the neck of the original containing vessel and dissolve the precipitate through the pad by the dropwise addition of 15 ml. of dilute ammonium hydroxide, finally washing the pad two or three times with hot distilled water.

Re-filter the ammoniacal extract through the same filter into a clean conical flask, washing thoroughly with hot distilled water (at least ten washes are required). Place the flask containing the filtrate on the hot-plate, together with a second flask containing 50 ml. of ammonium acetate solution and 50 ml. of ammonium-chloride solution. Bring both solutions to the boil and add to the ammoniacal extract 10 ml. of hydrochloric acid (sp. gr. 1·16), followed by 8 ml. of lead-acetate solution. (If a precipitate forms, clear the solution by a further addition of hydrochloric acid (sp. gr. 1·16), added dropwise.) Pour this solution into the acetate-chloride solution, rinsing thoroughly with hot water. Boil and allow the precipitated lead molybdate to settle.

Filter on an ashless paper-pulp pad, washing with hot distilled water. Dry, ignite at a temperature not exceeding 650° C., cool and weigh as lead molybdate, $PbMoO_4$.

Notes.—1. The weight of lead-molybdate precipitate multiplied by 0·35 equals the percentage amount of phosphorus if a 2-g. sample is taken.

2. The method eliminates completely the influence of arsenic in commercial steels.

3. Results obtained by the method are accurate to ± 0·0015% of the true phosphorus contents.

Determination of Lead in Steel

The Report concludes with a recommended method for the determination of lead in steel. This method, based on the initial separation of the lead as lead sulphate, and its subsequent conversion to lead molybdate, was subjected to rigid examination and experiment, and remarkably close agreement was obtained. The method is described below.

Solutions Required.—Ammonium-acetate solution: Dilute 1 volume of glacial-acetic acid with 2 volumes of distilled water and neutralise with ammonium hydroxide (sp. gr. 0·880): just acidify with the acetic-acid solution and finally dilute with an equal volume of water.

Five per cent. ammonium molybdate: Dissolve 5 g. of ammonium-molybdate crystals in 100 ml. of distilled water and make ammoniacal with a few drops of ammonium hydroxide (sp. gr. 0·880). Filter the solution before use.

Five per cent. sulphuric acid: Add 5 ml. of sulphuric acid (sp. gr. 1·84) to 85 ml. of cold distilled water; add 10 ml. of methylated spirit and dilute to 100 ml.

Procedure.—Cover 10 g. of sample in a covered 600-ml. squat-type beaker with 80 ml. of distilled water and add, cautiously, 20 ml. of sulphuric acid (sp. gr. 1·84). Digest until dissolved and fume for 10 min. Cool.

Add, cautiously, 200 ml. of hot water and boil to ensure complete solution of iron salts. Cool, add 50 ml. of alcohol (industrial methylated spirit) and stand for 2 hours.

Filter the lead sulphate on a paper-pulp pad, washing with 5% sulphuric acid containing 10% of alcohol.

Dissolve the lead sulphate through the pad by the addition of at least three portions of hot ammonium-acetate solution of 10 ml. each (allowing each to drain before adding the next), followed by several washes with hot water. Make the resulting solution alkaline by the addition of 5 ml. of ammonium hydroxide (sp. gr. 0·880). Boil and precipitate lead molybdate by the dropwise addition of 20 ml. of 5% ammonium-molybdate solution.

Filter on an ashless paper-pulp pad, washing with hot distilled water. Dry, ignite at a temperature up to 650° C., cool and weigh as $PbMoO_4$, containing 56·42% of lead.

Notes.—1. This method is not recommended for high-chromium steels.

2. It is unnecessary to report lead figures beyond the second decimal place.

3. It is recognised that in leaded steels segregation of lead occurs to an extent greater than the segregation of ordinary elements in non-leaded steels.

Tool Grinding

By A. J. Schroeder, D.Sc., D.Sc. (Eng.)

GRINDING and, closely associated with it, polishing are two methods of machining both metallic and non-metallic materials which have for long been used. We find grinding and polishing methods as important and essential operations in every stage of the development of manufacturing technique: beginning with man's production for his personal needs (i.e., flint hatchet, arrow-head, etc.) leading on to the craftsman's work, and so down to modern manufacture and industrial production. During the last decades of continuous and quickening progress, improvements in working methods have brought grinding technique in an ever-increasing degree into the foreground. We may maintain without exaggeration that the economical and, at the same time, qualitatively sound manufacture of many articles of consumption for daily requirements, and of nearly all means of production would be absolutely inconceivable without the grinding and polishing machines of our age, and without modern grinding media and grinding tools.

This becomes convincing enough if we imagine commonplace articles, such as razors, sewing-needles, household utensils, motor-cars, steam turbines, spinning-machines, rolling-mills, and airplanes being manufactured at the present price and quality, without resorting to modern grinding methods. Indeed, we can go a step further, and recognise that the above-mentioned important progress—not only in the grinding essential for the production of machine parts and other components, but also in the entire process of production—depends on one decisive factor. This is an advanced knowledge of grinding, and foremost in this branch of engineering is tool grinding.

To put the cutting tool into a condition in which it is at once both efficient and accurate in shape is only possible by the aid of a tool-grinding technique which is absolutely up to date. Thus, for example, the accuracy of gears and the quiet, smooth running of pinions will depend essentially on precision grinding of the facing cutter required for their production; or again, the pressed mudguard of a motor-car will be accurate in shape, and smooth in surface only in so far as the cutting tools used for producing the pressing die and the grinding machines and methods employed in the process will allow.

It is true, however, that to achieve outstanding results, both in quality and speed of output, other essential conditions must be fulfilled. To these belong principally the craftsmanship of the operator and the quality of the machine tool. These points in no way diminish, however, the significance of the condition of the machining tools, and, along with it, the importance of tool grinding. Both the initial grinding and subsequent dressings of the cutting tools require the most wide experience and modern equipment. Extensive varieties of special tools of many shapes are now made possible by the use of modern cemented carbides and diamond tools, apart from the simple steel tools.

If a workshop is content to use poor tools, such as damaged milling cutters, drills re-ground by hand, turning tools provided with wrong angles, or machines with blunt or loaded grinding wheels, it can be concluded fairly correctly that first-class produce can never issue from this workshop.

In all production operations the tool is the part bearing the greatest stress. It is, therefore, easy to understand the simple contrast in life between a machine and its tools, regardless of the repeated renovation of the latter. It is unfortunately only too true that this high stress, affecting the whole manner of treatment of the actual tools, is too often insufficiently considered.

Only a comparatively short time ago the precision of work amounted to a latitude of as much as 0·004 in. under the most favourable conditions; the demands made on machine tools were small, according to the stage of machine tools then developed. The requirements added in the last decades, however, have not only influenced the machines, but also necessitated the application of far more rigid standards in regard to the criterion of all tools.

Increased capacity and increased precision are the two ideals which have become the aim of every toolmaker. High-speed steels and cemented carbides have been developed to an amazing output capacity. But these highest attainable capacities are only reached when the highly stressed tools are in their best condition. In this connection extensive education on a broad basis is still required in the workshops. For, doubtless, many failures occurring even now in spite of new high-speed tools are attributable to incorrect maintenance or unsuitable treatment during grinding.

Lastly, these problems have very important consequences when considered economically. It has been ascertained by research and in practice in how considerable a degree the efficiency of tools depends on their condition. This efficiency is definitely proved by specifying the life of the tool in question for machining a certain, constant material under fixed conditions up to the time of the blunting of the tool. Also the surface smoothness of machine faces sliding one upon the other have been regarded with growing interest. The acme of perfection of such surfaces can only be attained by means of fine finishing of the cutting tools when they are carefully ground.

Experiments have been carried out in abundance with many kinds of tools. Among other things they have proved statistically by means of the most carefully made deductions what the production engineer had already known through long experience and by instinct. This was, that even small defects—for instance, in the chamfered edge of drills or any faults in the cutting angles of tools are sufficient to reduce the cutting capacity to a fraction of the efficiency obtainable by perfectly ground tools. In a higher degree, correct grinding and suitable treatment are essential for obtaining the capacity required for cemented carbides.

To-day, tool-grinding is a matter of primary importance, and demands the repeated truing up after wear or possible injury by workmen trained in this special subject. The consequence is, therefore, that tools, and particularly the higher-grade tools, should not be ground by the operators using them, but always by a specially instructed staff in the tool-room, or a corresponding department. The time is past when every turner had his own shape of lathe tool, which he made by supposedly clever methods on the completely unsuitable emery-wheels. To-day, it is much more difficult to prepare the tool in the best way in the workshops to meet all the requirements that are necessitated by the use of modern cutting materials of metallic and non-metallic structure.

Large portions of expensive tools are often ground off uselessly. These consist, almost without exception, of high-quality structural materials from abroad, and it is, therefore, a national duty for everybody to treat these tools properly, so that they do a maximum of work.

The sinking of ever-increasing amounts of money in tool equipment has been a feature of the current trend of technical development. This necessitates economy, especially in war time, in the use of expensive means of production. These causes conduce the demand for enlightenment, expert training, and education to grow incessantly.

Further articles will be published in subsequent issues containing numerous suggestions and instructions drawn from modern practice on correct and efficient grinding of tools, which should provide the interested circles with information which will take the place of instructions hitherto scattered over many different publications.

Heat treatment in South Australia

At the British Tube Mills, Kilburn, South Australia, they use a Multelec six-point temperature recorder on their heat-treatment furnaces

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GEORGE KENT

HEAT TREATMENT
PROCESSES — PRACTICE — PLANT

May, 1942 METALLURGIA Vol. XXVI, No. 151

ALMOST every phase of manufacturing or processing has some problem which involves the application of heat, where metal products are concerned heat is necessary in almost all the processing operations from the smelting of the ores and subsequent refining of the metal, through the various stages to the finished product. Correctly applied heat contributes to the refinement of the material, and not only permits the casting, forging or stamping into the wide variety of shapes needed in industry, but, as a result of work on the material it makes possible, improved structure of the material and enhances its physical properties Thus, it can be said that the application of heat in the production of ferrous and non-ferrous products is of fundamental importance in facilitating production and in improving the quality of the finished product. The term heat-treatment, in its widest sense, concerns all operations in which metals and alloys are heated, in the narrower sense, however, and that with which we are more especially concerned here, the term is applied to processes by which metals and alloys of suitable composition can be modified to produce desired physical properties. But it should be appreciated that the improper use of heat in the various processes which precede heat-treatment proper can prevent the desired properties being obtained by subsequent heat-treatment. Actually, careless and indifferent heating for the many fabricating operations can have a great influence upon the heat-treating and machining operations and upon the results obtained in service with the finished products.

Among the most important effects of heat is that of changing the state of a substance from a solid to a liquid, in heat-treatment, however, its effect is to change the structure by transformation to establish another phase, by changing the character of the compound or compounds in solid solution. Fundamentally, heat-treatment does not affect a chemical change in the material, but it is used to contribute to a change in chemical composition. Thus, for instance, heat-treatments to produce surface hardening, such as carburising, cyaniding, nitriding and such operations do effect a change in chemical analysis, since carburising introduces additional carbon to the surface layer of steel; in cyaniding both carbon and nitrogen are picked up; while in nitriding nitrogen is diffused in the surface layer of particular steels. Apart from these exceptions, it is the structure of ferrous and non-ferrous alloys that is modified by heating and subsequent cooling, and it is by control of these operations that the desired properties can be produced.

In the majority of heat-treatment processes an improvement in several properties is sought, and, as no one treatment will give the maximum for each property desired, a compromise must be effected, so that the result will comply with specification requirements. The ferrous and non-ferrous alloys, which are regarded industrially as strong, depend upon the improvements in mechanical properties, which can be effected by heat-treatment. Thus, for instance, the response of certain aluminium alloys to heat-treatment, first discovered by Wilm in 1909, has had an enormous effect on the light-metal industry, especially on the progress of aeronautical engineering. The mechanism by which these modifications to properties occur has been investigated. It is known that certain constituents of aluminium alloys, notably the copper-aluminium compound $CuAl_2$ and the magnesium-silicon compound Mg_2Si are soluble in aluminium to a much greater extent at high temperatures—approaching the alloys' melting-point—than at low temperatures. If the alloy is at high temperature for a period sufficiently long for the solid solution of these constituents to take place, and is then rapidly cooled by quenching in water, an artificially high amount of constituent remains dissolved throughout the mass. This solid solution, however, is not stable at room temperatures, and the result is that the compound or element in excess tends to be precipitated in sub-microscopic form. The precipitation of these compounds appears to have a "keying" action between internal slip planes, helping to prevent or regulate motion and thereby increase the mechanical strength and in some cases ductility of the material. The extent of this natural precipitation or ageing, as it is more commonly termed, and the temperature at which it will take place, can be determined largely by adjustment of the chemical composition, and two main types of heat-treatable aluminium alloys have been developed: that which increases in strength spontaneously, reaching a maximum in four or five days, following a high temperature treatment and quench in water, and that which is given a double heat-treatment, the second of which is a precipitation treatment, carried out at a lower temperature.

Fundamentally, the principle is somewhat similar in the heat-treatment of steels, the main forms of which are annealing, normalising, hardening and tempering. The temperature at which the particular operation is carried out depends upon the composition of the steel, but the success of the process depends upon time as well as temperature. Obviously, it is necessary that the steel undergoing treatment should be uniformly heated, and while this is simplified in the case of thin sheet, strip or wire, since there is no appreciable mass effect, the problem becomes more involved with the increased thickness of the material. Thin material can be heated to a uniform temperature almost at once, whereas in thick sections the heat must be conducted from the outside surface towards the centre and time becomes a very important factor; thus, the material must remain in a furnace held at the required temperature until it is completely soaked, and care must be exercised to prevent overheating of the surface material.

For straight carbon steels, the temperature for a full anneal varies with the carbon content; for a carbon content of 0·8% the temperature is very near to 760° C., but increased temperatures are necessary when the carbon content is above or below this point. The temperature of the material should be uniform, and it is important that cooling from the full annealing temperature be slow to give time for the transformation to take place. In normalising the temperature is generally higher than for a full anneal, and cooling is more rapid. This is frequently a final treatment to give the steel the mechanical properties desired, but it may be used to refine the structure of forgings and to make it more uniform, so that any subsequent hardening treatment may be carried out with the minimum of distortion. The full hardening of steel involves a quench from above the critical temperature range; in this condition the steel may be in a highly stressed state, and relief is effected by a tempering treatment which also allows the finely dispersed carbide to coalesce, which increases the toughness of the steel, and the tempering temperature used determines the degree of toughness.

Although, strictly speaking, no new heat-treatment processes have been developed in recent years, improvements are being effected continuously especially in the plant used for the many operations, and in this issue attention is directed to some important aspects of this complex subject.

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Heat-Treatment and Work-Effect on Steel

By Bernard Thomas, F.Inst.P., F.Inst.F.

While the sage who quoted that hard work never killed man may have been right as far as the human element was concerned, his views would need revision in the case of steel, for too much work can prove injurious, just as in reverse too little is equally bad. The object of these remarks is to discuss how too little work on a cast of steel gave rise to considerable difficulties : secondly how overwork in another case interfered with normal heat-treatment : and thirdly, how the judicial application of work to an overheated consignment rectified the structure sufficiently to yield satisfactory physical figures.

IN the production of billets for the drop-forging industry most steelmakers roll the whole range of sizes from, say, 1½ in. to 6 in. square from their one size of ingot, which obviously indicates the possibility of variation in the amount of work applied between the smaller and larger sizes. The saving feature is, however, that, in the majority of cases, a billet is subjected to an intermediate rough-shaping process, known in the trade as " dummying " before stamping, and such working on the billet is usually sufficient to remedy any deficiency which may have existed previously.

For the production of small forgings, however, a stamper will often choose a round or square of small cross-sectional area and make a stamping directly without the intermediate dummying process. By this means less work is applied. The earlier remarks would suggest that the use of a small section in itself would be enough to warrant that the structure had been worked sufficiently, and at one time this would have been the case. Unfortunately, however, the rapid growth in electric steel output has brought in its trail, in certain directions, the production of ingots of relatively small dimension, and cases are coming to light where the actual final forgings are still possessed of a dendritic structure solely due to lack of work in the prior rolling stages. The latter is stated advisedly because, quite obviously, the stamper, being limited to a set number of blows in order to produce his forging, cannot be expected to supplement the earlier deficiency.

In a recent case where the writer was concerned in an advisory capacity, a consignment of forgings had been rejected on the grounds that the material had been over-heated during heating for forging. The steel in question was to Specification S67, which, as Table I will show, is a 5% nickel case-hardening type.

After the production, the forgings concerned had been normalised at 830° C. in routine manner as laid down by the specification, but unfortunately not only was the fracture almost entirely crystalline and coarse, but the core had a peculiar whitish appearance reminiscent of segregation in a rolled section. Sulphur printing proved the absence of the latter, but quite obviously something was amiss, and after a second normalising had failed to remedy matters, a micrographical examination was made, the results of which follow.

TABLE I.
SPECIFICATION S67.—5% NICKEL CASE-HARDENING STEEL.

Carbon	0·08—0·14%
Silicon	0·30% max.
Manganese	0·35% "
Sulphur	0·05% "
Phosphorus	0·05% "
Nickel	4·6—5·2%
Chromium	0·10% max.

Fig. 1 is a photomicrograph of a cross-sectional area of one of the affected forgings in the condition obtaining after the standard normalising treatment at 830° C. Reference to this will show the presence of angular dendrites, suggestive of an ingot structure, and certainly having no place in a normalised forging destined for aircraft duty. In no part of the whole field explored was to be found evidence of either overheating or burning, which fact pointed to an earlier stage of manufacture as being the initial cause For reasons outlined previously, it is conceivable for steels to suffer in this manner, but the point next arose as how best to rectify the consignment rather than have it scrapped.

The simplest way, and one which was expected to be effective, was to again normalise, in the hope of cumulative action. This brings in the question of temperature The writer holds certain views in this respect concerning which data may be given at some subsequent period, but for the moment it is explained as the reason for the re-normalising being carried out at 780° C — i e , 50° C. less than called for by the ruling specification.

The subsequent metallic fractures were of an unsatisfactory conglomerate nature, largely crystalline, although the latter were small in character, but having the same tendency towards whiteness which characterised the original test. Still unsuccessful, as was borne out by Fig. 2,

Fig. 1.—S67, 5% Ni steel as routine normalised by the forger at 830° C. × 300.

Fig. 2.—The same steel renormalised at 780° C. following the treatment given in Fig. 1. × 300.

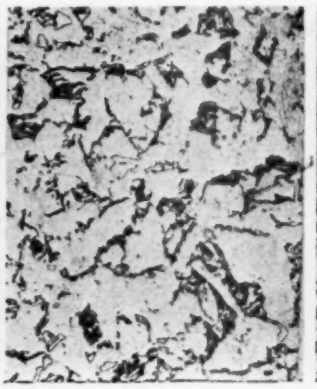


Fig. 3.—The same steel renormalised at 850° C. following the treatment given in Fig. 1. × 300.

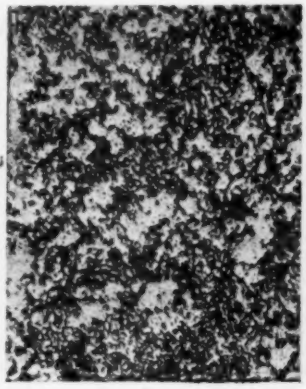


Fig. 4.—The same steel after 10 hours' soak at 670°—680° C. and furnace-cooled after treatment given in Fig. 1. × 300.

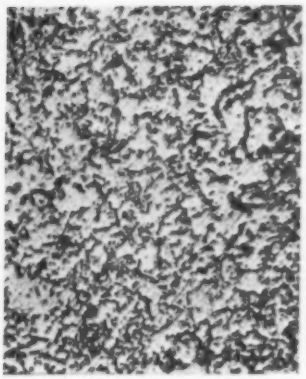


Fig. 5.—The same steel as normalised at 780° C. after the treatment given in Fig. 4. × 300.

Fig. 6.—The same steel as normalised at 850° C. after the treatment given in Fig. 4. × 300.

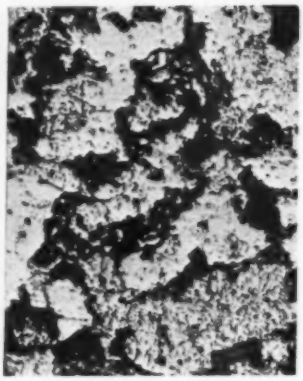


Fig. 7.—The same steel after annealing 5 hours at 1,050° C. × 300.

which can scarcely be regarded as acceptable for a 5% nickel mild steel!

To meet the critics of low-temperature treatment, a repeat effort was made at 850° C., the result of which showed that not only was a greater percentage of the fractures crystalline than from 780° C., but they were definitely of coarser nature. Reference to Fig. 3 shows a marked change in structure, bearing out the appearance of the coarser grain mentioned.

There was still present in the fracture the dull white appearance regarded as unsatisfactory, and the persistency of this, coupled with the angularity of the ferrite areas in Fig. 3 decided the writer to recrystallise the grains, as it appeared obvious that despite having reached the austenitic condition, by reason of the 850° C. employed during the normalising, the time of the operation was too brief to totally destroy the ingotism effects. Accordingly, therefore, the decision was put into practice by soaking for 10 hours at 670°–680° C. and furnace cooling, the full cycle including heating of the load, taking 24 hours to complete.

The foregoing treatment yielded a structure roughly 90% crystalline, but of a very fine character, and in which no traces of ingotism remained. Although representing progress, Fig. 4 revealed the pearlite in spheroidised condition, and, in any case, a higher impact value was desirable than that indicated by the finely crystalline break.

A nominal normalising was now executed, employing once more the lower temperature of 780° C. Success at last! Fractured forgings showed literally an ideal silky "textbook," 100% fibrous structure, with fibres resembling those in a good wrought iron, but much finer. Perfection, as near as could be achieved with any steel, as is borne out by Fig. 5.

The story should end at this note, but, again, to meet possible critics, two further tests were put through to round off the work. Firstly, a nominal normalising at 850° C. following recrystallisation, which, though producing a fibrous structure, was less fine, and therefore inferior to the result of treating at 780° C.; Fig. 6 confirms this point. Secondly, as an independent school of thought advanced the theory that the only hope of salvaging the forgings lay in annealing for 5 hours at 1,050° C., the writer carried out a trial along these lines, although not subscribing to the theory. The result showed very coarse fractures, 100% crystalline and completely unsatisfactory, and Fig. 7 serves as confirmation.

Summing up the situation, evidence has been shown that in such cases where there has been insufficient work on a steel in its manufacturing stages to remove ingotism, and forgings are produced before the trouble is located, it is not necessary to have the latter scrapped off-hand, as correctly applied heat-treatment may be utilised to rectify the grain.

Effect of Excessive Work on Material

So much for lack of work Attention now is drawn to another case where material suffered in the opposite direction—i.e., heavy working had crushed the grains to an extent that it failed to respond to hardening treatment as normally expected

The case in point involved steel to the upper limits of 5005/203, treated to yield 5005/204 figures, composition of both being given in Table II to refresh the memory

TABLE II.
CHEMICAL COMPOSITIONS SPECIFIED.

Element.	5005/203.		5005/204.
Carbon	0·35—0·45%	..	0·35—0·45%
Silicon	0·30% max.	..	0·30% max.
Manganese	0·40—0·80%	..	0·40—0·80%
Sulphur	0·06% max.	..	0·06% max.
Phosphorus	0·06% max.	..	0·06% max.
Nickel	1·00% max. (optional)	..	0·30—1·00%

The circumstance which brought the matter to light was due to a trial made with a view to producing a certain type of tool in small diameter rolls only one-fifth the diameter of that employed as standard, but running at a greatly increased speed, the object being, of course, to increase production and reduce costs.

Fig. 8.—5005/203 steel, longitudinal section as received from steel suppliers, showing banded structure. × 200.

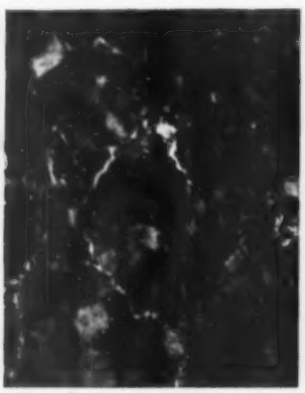


Fig. 9.—The structure produced from the steel shown in Fig. 8 by the normal method of production. Longitudinal section. × 200.

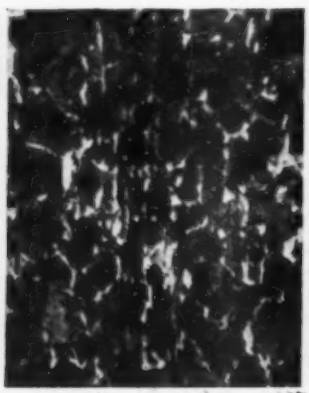


Fig. 10.—Structure resulting from "spreading" action on steel shown in Fig. 8. Longitudinal section. × 200.

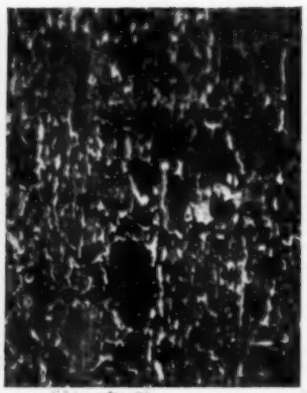


Fig. 11.—Effect of "lengthening" of that shown in Fig. 10. Longitudinal section. × 200.

From an engineering view-point, the idea was an eminent success Unfortunately, however, when the products came to be hardened and tempered, the usual response was not forthcoming, and whereas one normally found it possible to attain D.P.N. readings up to 650–700 by quenching in fused salts, it was necessary in some instances to resort to a water quench to obtain only 500–600 D.P.N., and withal the results were inconsistent. Obviously, a metallurgical matter, and routine micrographical examination revealed the trouble.

Fig. 8 shows the rolled structure as received from the steel suppliers, with the typical ferrite bands and elongated areas of manganese sulphide. Somewhat far removed from the ideal admittedly, but quite the common thing in basic open-hearth material. Fig. 9 shows the result of production under the hitherto normal conditions. the banded structure being completely broken down and replaced by a network of grain boundaries. These two photomicrographs serve as an excellent example of the effect work can have on steel

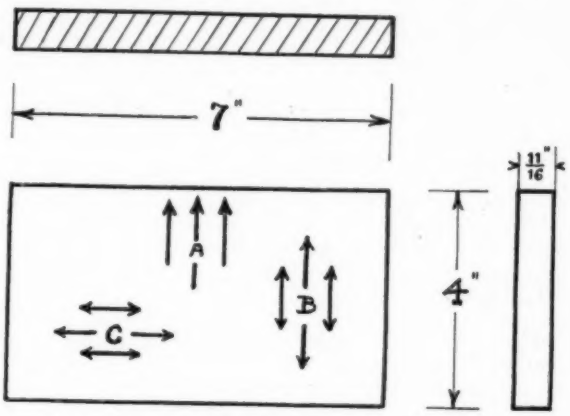


Fig. 16.—Showing directions of rolling, etc.

between the raw material supplied and the produced article without the application of heat-treatment as such.

In order to grasp more fully the object of the working in the trial, reference should be made to Fig. 16, which gives dimensions of the rough section upon which work is commenced. The arrows A indicate the original flow of grain, or direction of rolling, as is revealed in Fig. 8. Arrows B show the direction of pass in the first operation, which really amounts to one of " spreading " the metal. Arrows C represent the second operation following B and which becomes one of elongating or " lengthening " the " spread " steel. The final dimensions are naturally somewhat irregular, as may be imagined, but may reach 14–16 in. long × 9–10 in. wide × 0.12–0.14 in. thick. The surplus metal is employed in forming a certain impression at one end only, but being irrelevant to the subject, is omitted from these remarks.

Fig. 10 shows the structure resulting from the " spreading " action, which forms only part of the work required. Although the heavily banded ferrite areas are broken down, it is still possible to discern the direction of rolling. Examination was made in the same direction as arrows point.

Fig. 11 is the structure of the " lengthened " section following the spread as shown by Fig. 10,

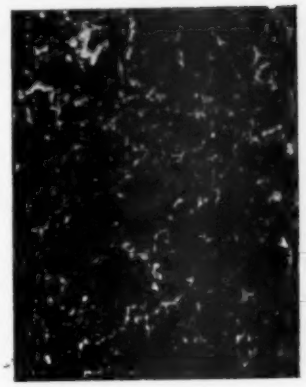


Fig. 12.—Section at right angles to that given in Fig. 11, to show cross-section. × 200.

Fig. 12a.—Same as Fig. 12, but a different micro-field. × 200.

again photographed in same direction of arrows B to be comparable with Fig. 10. It was a curious feature that the cumulative effect of spreading the original rolled structure was so marked that the work at right-angles as represented by C in Fig. 16 was insufficient to destroy it, in fact the appearance is rather more marked than in Fig. 10. Attention is drawn also to the badly crushed grains.

Fig. 12 was photographed from the same micro-specimen as Fig. 11, but from a field at right angles thereto, and upon this occasion in the same direction of arrows C. Fig 12A is as Fig 12, but of a separate micro-field Indications of directional effect are slight, the net result showing conclusively that the joint effect of " spreading " B following original rolling A is too strong for " lengthening " C to destroy.

The effect of the new method of production was therefore to produce structures as represented by photomicrographs Figs. 11, 12 and 12A, in comparison with that as obtained previously, as shown by Fig. 9. The reduction in grain size and their crushing is due, of course, to the increased work effect brought about by the higher speed of output of the smaller rolls, and explained why the normal heat-treatment cycle was unable to obtain the usual response.

Having ascertained the cause, the remedy next follows. Normalising was indicated as the immediate solution, but while this showed some improvement, the effect was incomplete, and after routine experiments it was found necessary to submit the produced tools, prior to hardening, either to a treble normalising, or recrystallise completely the grain by an annealing cycle of 670°–680° C., followed by slow cool.

Fig. 13.—5005 / 203 steel. Condition as received from supplier showing enlarged grains and traces of burning. × 150.

Fig. 14.—Effects of forging described on the steel shown in Fig. 13. × 150.

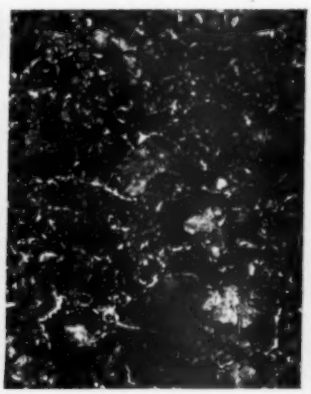
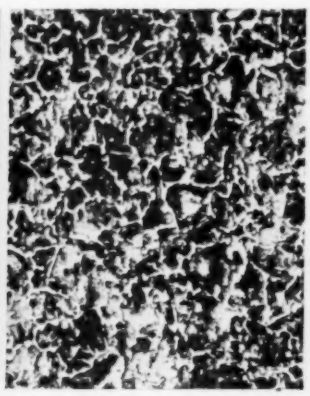


Fig. 15.—Normalised structure of the same steel. × 150.



Effect of Overheated Ingot

The third case concerns a consignment to 5005/203 specification, which had been so overheated in ingot form, prior to rolling, that the resultant products were of such brittleness that tempering failed to rectify.

Fig. 13 shows the result of micrographical examination, and reveals evidence of burning at grain boundaries. Such evidence was confirmed by the inability of normalising to rectify, and, theoretically at least, the only remedy for a burnt steel is remelting. Necessity was ever the mother of invention, however, and fortunately the work in hand lent itself to being hammer-forged as an alternative method of production. Such forging was therefore put into process under a pneumatic hammer of Broadbent type dealing 230 7-cwt. blows per min.

The structure after such work effect had been introduced by the forging described was that as shown in Fig. 14, which at the same magnification is a vastly different proposition to the burnt grains in Fig. 13. Gone were the traces of burning, but there remained some risk of lack of response during heat-treatment, and in consequence normalising at 830° C. was introduced, producing a reasonable finish ready for hardening, as depicted by Fig. 15.

In conclusion, it has been shown that steel suffering from lack of work may be rectified by heat-treatment of suitable character, effects of too much work may be remedied in similar manner, and finally, a steel slightly burnt, and therefore of doubtful nature, has been salvaged by the joint action of work effect in the initial stages, followed again by heat-treatment to complete the action. It may be appreciated, therefore, from these remarks just how important a place is occupied both by work-effect and heat-treatment in modern industry.

The Application of Atmosphere Control to the Hardening of High-Speed Steel

By A. H. Holden, B.Sc.

The use of controlled atmospheres in various heat-treatment processes is now established in the treatment of both ferrous and non-ferrous materials. The main object is to preserve the condition of the surfaces of the material undergoing heat-treatment. This is especially important in the hardening of high-speed steel, and practical problems involved in the application of one method of atmosphere control for this purpose are discussed.

MUCH attention has been directed to the use of controlled atmospheres in recent years, in the hardening of high-speed steels, particularly with the method developed and subsequently patented by the Sheffield Gas Company. Most of the literature dealing with this development is concerned with the general principles involved and their theoretical considerations; in this article, however, the practical problems involved in the application of these principles to a recently installed battery of furnaces are discussed. In view of the growing popularity of this system of hardening high-speed steel, and, bearing in mind the greater need for protecting the surfaces of the steel to be treated, due to the increasing use of molybdenum in its composition, it is thought that a description of a typical installation, together with some practical details of the operation of such a plant based on experience gained over an extended period will be of value.

The Plant

The plant concerned is located in the hardening shop of a large firm of tool-makers whose works are situated in the Midlands. The furnaces are disposed on opposite sides of one-half of a long and comparatively narrow hardening shop, the oil quench tanks, air blast, quench boxes, etc., occupy the centre of the shop, while the instruments indicating, recording and controlling the furnace temperatures are mounted on a panel across the end of the shop.

Three types of furnace are installed, each being for a particular hardening duty. There are double chamber horizontal muffle furnaces, each with a preheating and a high temperature chamber, jobber drill furnaces with three preheating chambers and a single high temperature muffle, for the treatment of small drills, and finally vertical pit type furnaces in which larger drills, broaches and reamers are hardened. Each unit of the latter consists of two separate furnaces—a double chamber preheating furnace, and a single chamber high-temperature hardening furnace which is installed close to the preheating furnace.

Preparing the Protective Atmosphere

The method of preparing the protective atmosphere of the type governed by the Sheffield Gas Co.'s patent consists essentially of adding a certain small percentage of unburnt town's gas to the dehydrated products of complete combustion of town's gas. The percentage of unburnt gas required decreases with increase of furnace temperature, and different steels require atmospheres of different compositions; it is not practicable, therefore, to supply a number of furnaces from the same complete atmosphere preparation unit. The dehydrated products of combustion, however, are common to all protective atmospheres used in high-speed steel hardening by this method, and therefore a central unit is installed wherein town's gas is burnt with the correct amount of air required for complete combustion, and the resultant products dehydrated. This consists of a cylindrical brick-lined combustion chamber with a burner firing tangentically fitted at the bottom, the top carrying the products outlet pipe. This outlet conducts the hot products of combustion to a direct type cooler, in which the ascending gases meet a descending spray of water. The cooler is filled with coke to ensure intimate mixing of the water and ascending products of combustion. The gases are washed as well as cooled, and the major portion of the sulphur compounds (mainly as sulphur dioxide) are removed by solution in the cooling water.

Intimate contact with water would not appear to provide an efficient means of removing water vapour, but when it is remembered that the products entering the cooler are saturated with water vapour at a high temperature, and therefore, on cooling, much of this water will be removed, it will be readily appreciated that a direct cooler will be more efficient than an indirect one. The lowest limit of water vapour content that it is possible to attain by the use of water as a cooling agent is naturally that corresponding to the percentage of water vapour present in the products saturated at the temperature of the cooling water. This is obviously more easily obtained in a direct than in an indirect cooler. It is possible to reduce the water vapour content to about 1·8% by this means. Such a small percentage has little apparent action on the steel, and such as there is can easily be checked by adding raw gas.

The cooled products pass into a products main which extends round three sides of the hardening shop—the supply being maintained by the pressure set up in the combustion chamber helped by the syphon effect of the cool products leaving the cooler. Separate supply pipes are

taken to each furnace. The total volume of products is controlled by the air cock to the combustion chamber burner on the unit. As this burner is of the surface combustion automatic proportioning type—the composition of the products is constant within the required limits at various degrees of turn down. The atmosphere preparation unit is installed in duplicate, so that when repairs or cleaning are necessary, the spare unit can be put into commission and hardening carried on as usual.

The unburnt gas is supplied to each furnace by means of a pipe from the main round the shop—passing through a low-pressure service regulator, which is set to give a pressure of 0·75 in. water gauge on the outlet side. This low pressure has two advantages—it prevents fluctuations in gas pressure which the varying demands made by the furnace on the main gas supply might cause, and secondly, it decreases the sensitivity of the fine adjustment valves controlling the admixture of unburnt gas and therefore makes fine adjustment much easier. To maintain constant atmosphere to each furnace, it is necessary to leave the products cocks open, whether a furnace is working or not, as the increased pressure which would be caused by closing the cocks on a furnace, could upset the proportions of unburnt gas to products in the furnaces left working. It was first intended to maintain this pressure constant either by governors to each furnace or by a flap type pressure release valve on the unit, but in practice the pressure of products in the system is so low—about 0·4 in. water gauge—that neither of these methods is practicable.

The apparent waste of products caused by this method of maintaining constant conditions causes no appreciable increase in running cost, and can, of course, be reduced by adjustment of the burner on the unit. For short-time shut-downs this latter method is seldom worth while.

Practical Operation

All the furnaces are of the complete muffle type, therefore the adjustment of the gas/air ratio supplied to the burners is not critical, and, as surface combustion low-pressure equipment is used, this adjustment is very simple, and can be done merely by the turn of a screw. When correctly set initially, this ratio requires no further attention, and remains reasonably constant over a wide range.

Control of the burners is effected sclely by means of the air cocks, the gas cocks being wide open whenever the furnace is working. No gas analysis is really necessary to adjust the gas/air ratio for maximum efficiency—the best guide being the nature of the flue gases issuing from the ports on the furnace. A distinct flame denotes an excess of gas—which should be cut down by means of the gas adjuster until it is on the point of disappearing—a slight haze should be visible when the furnace is at working temperature.

The initial adjustment of the gas/air ratio to the burner on the combustion chamber of the atmosphere preparation unit is carried out in a similar manner, but as there is no flue outlet, the criterion can be the hot products issuing from the peep-hole in the door of a horizontal muffle furnace at working temperature, with products admitted to the muffle only—no raw gas. Here again a slight haze—just bordering on a flame should be visible. This denotes that the products are slightly on the reducing side and will therefore contain no oxygen. A temperature of 1,050°–1,100° C. in the combustion chamber of the unit has been found to give the best results. The products of combustion now being correct, the next consideration is the water supply to the cooler.

It is readily appreciated that the lower the temperature of the gases leaving the cooler, the dryer they will be. To ensure this it is necessary that the water supply be as cold as possible and in sufficient quantity to extract as much of the heat as possible. Care must be taken to ensure that the flow is not more than the outlet can carry away. One method of preventing this latter is to break the water supply—that is, feed the water from the mains into a funnel leading into the cooler through a syphon trap to prevent gas leakage. This will limit the head of water flowing into the cooler to the same as that existing inside, and prevent the level rising.

Furnace Operation

Temperature.—Of the three possible variables that require fixing for the successful hardening of high-speed steel—the first, temperature, is easily settled, as the steel-makers state the correct hardening temperature for each type of steel. All the atmosphere controlled furnaces are fitted with automatic temperature control, and it is only necessary to set the controller to the required temperature—which will thereafter be maintained constant. It may be worth noting in connection with automatic temperature control that nost furnaces are fitted with the "on" and "off" type of control valve with a separate by-pass. A more constant temperature is maintained with this system, if the maximum and minimum consumptions are set as close as possible, with the proviso that the minimum gas rate should not allow the desired temperature to be exceeded during stand-by periods.

Time.—The second factor to be considered is the time the work should be left in the furnace. As regards pre-heating—it is necessary that all tools should be thoroughly soaked at about 850° C. before being transferred to the high temperature chamber. A preliminary warming up on top of or in front of the furnace may also be carried out with advantage, particularly in the case of tools of large section or intricate design. The time required in the high-temperature chamber can only be found out by experience, as this is dependent in a large measure on the size and shape of the tool, and, to some extent, on the composition of the high-speed steel.

It is obviously not possible to allow heavy tools, with any projections of thin section, to reach the furnace temperature throughout as that would result in the thinner parts being over-soaked. With the atmosphere controlled furnace there is less danger of overheating and longer times at the hardening temperatures are permissible than in an open-fired furnace. The time will vary from a few seconds in the case of small tools of thin section to several minutes in the case of heavy tools. Timing clocks are installed in the hardening shop described to ensure uniform soaking times for similar tools, as repetition work is usual, particularly in the case of twist drills.

Atmosphere.—Considering now the question of correct atmosphere, the third variable of which the significance is not as generally appreciated as that of the two just discussed, it must be understood at the outset that some careful experimental work is necessary in the case of each atmosphere controlled furnace installed, before any one of a variety of tools of differing steels can be hardened with confidence of success. As an example of the widely differing atmospheres used with steels of different composition, the following analysis of actual results is perhaps illuminating.

Steel Analysis.					Hardening Temp.	Gas Analysis.				
C.	W.	Cr.	V.	Co.	°C.	Co_2.	O.	Co.	H.	N.
0·71	18·0	4·28	0·8	—	1,300	5·0	Nil	10·6	8·61	76·3
0·73	19·2	4·4	1·5	5·8	1,340	8·9	Nil	3·1	1·6	86·4
0·73	20·0	4·8	1·6	10·56	1,340	8·9	Nil	3·1	1·6	86·4
0·71	21·72	5·0	1·8	17·9	1,350	9·6	Nil	3·5	Nil	86·9

These figures are only given by way of illustration, and are not intended to be used as a means of setting the atmosphere. To set the atmosphere by gas analysis, although theoretically possible, would be a lengthy task, and can be done much more easily and with a greater likelihood of success by other means.

A brief survey of the various reactions involved in the hardening of steel in a controlled atmosphere will perhaps make the operation of the furnace clearer. The gases produced by the complete combustion of town's gas comprise what is commonly known as a neutral atmosphere, but

in their action on steel at elevated temperatures, such a mixture is far from being neutral. Of the three gases, nitrogen, water vapour, and carbon dioxide, only the first-named can be said to have no action. The passage of the products of combustion through the cooler thus reducing the water vapour content, prevents, to a large extent, the scaling and decarburisation that its presence would entail. The remaining gas, carbon dioxide, also causes scale formation and does decarburise, but it is not such a powerful agent in these respects as the water vapour, the amount of which has been reduced to a very small percentage. To prevent these two gases (carbon dioxide and a small percentage of water vapour) having any scaling action at all, and also to prevent them from decarburising the surface of steel, requires the addition of a small amount of unburnt town's gas. This addition to the dried products results in reactions between the gases at the elevated temperatures existing in the muffle, producing, finally, ratios of the resulting gases, which are in equilibrium not only with the iron in the steel, but also with the carbon and complex carbides. Mixtures of gases that are in equilibrium at any temperature with most of the steels in common use can be readily obtained by varying the proportion of unburned gas to cooled products.

It must be appreciated that the use of such an atmosphere does not entirely prevent both scaling and decarburisation, but is a practical compromise whereby the surface damage caused by either of these reactions is reduced to such a small amount as to be negligible. No atmosphere derived entirely from town's gas is capable of preventing both scaling and decarburisation at high temperature, although for the times usually employed in hardening high-speed steel the action is very small indeed. Scale formation can be limited to 1/10,000 of an inch, in which case decarburisation is absent. If sufficient unburned gas were added to completely prevent scaling at high temperatures the amount of hydrogen added—i.e., as the major constituent of town's gas would so raise the hydrogen/carbon monoxide ratio that decarburisation would result. At low temperatures this disadvantage is not so apparent, as below 850° C. there will be some methane undecomposed which influences the hydrogen/carbon monoxide ratio to such an extent that sufficient excess gas can be added to prevent scaling without causing decarburisation, provided the time of heating in the atmosphere is short. At the high temperatures used for hardening high-speed steel, the reactions in the muffle between the various gases of the mixture result in an atmosphere of which the major active components are carbon monoxide and hydrogen, the amount of the former being much in excess of the amount of hydrogen.

As carbon monoxide is a carburising gas and hydrogen is decarburising, both of these will prevent scaling, and, further, there must be some ratio of the two which will be in equilibrium with the carbon in steel, and will therefore neither carburise nor decarburise. When existing in this ratio the reactions on the steel of the two individual gases are equal and opposite, and therefore their combined actions have no deleterious effect.

Town's gas contains methane and other hydrocarbons which are decomposed by heat, and the rate of decomposition increases with increase in temperature. It follows, therefore, that as each volume of methane, for example, produces two volumes of hydrogen the greater the temperature the greater the quantity of hydrogen present. The amount of carbon monoxide formed also increases with temperature, but not to the same extent, and therefore if equilibrium is to be maintained at a higher temperature less unburnt gas will be required to produce the balance described above. The major component of the atmosphere is the dry products of combustion—the composition of which is constant and therefore the method of altering the ratios of the gases making up the atmosphere is by an alteration in the amount of unburnt gas added to it. This, then, is the only variable, and there is no better method of determining this setting than by trial with small test-pieces of the steel it is desired to harden. Experience has shown that pieces of $\frac{3}{4}$ in. square bar 2 in. long are quite satisfactory for this purpose, and for the test are left in the furnace 3 mins. if the temperature is below 1,300° C., 2 mins. when the steel is of the type requiring temperatures in excess of this. As these times are much greater than the hardening times necessary for pieces of steel of this size, the test is a fairly exacting one.

A first test should be carried out with an amount of unburnt gas added that will give an orange-coloured flame at the peep-hole in the furnace door. The results of the first test decide in which direction the change in atmosphere is to be made. If the test-piece is scaled unduly, more raw gas is required ; if it is clean but decarburised less raw gas. The standard 18 : 4 : 1 high-speed steel is less susceptible to decarburisation than the others in general use, and is therefore a good steel for preliminary experimental work. The atmosphere which is found to give good results with this steel is the richest in unburnt gas ; all other high-speed steels will require less, particularly (except in the case of 6–9% molybdenum steels) as the temperature will be higher. The atmosphere of the preheating chamber is less critical, and considerably more unburnt gas can be added without decarburisation, thus reducing scaling during the preheating operation. It must be borne in mind, of course, that some care is necessary in the adjustment as the preheating time is much longer than the hardening time for any particular tool.

The three variables have now been fixed, and it is recommended that details of each are entered on the job card accompanying any batch of tools to the hardening shop. Rarely will the large variety of tools to be treated be so large as to make this impracticable. The job card will therefore state the hardening temperature, the soaking time, the furnace number, and the fine adjustment valve setting for that furnace to give the correct atmosphere for the variety of steel. Definite instructions like these will go a long way towards removing the fourth possible variable—the human element in the person of the furnace operator.

Substitute Steels

I am indebted to Dr. H. A. Fells, of the Sheffield Gas Co., for a recent communication describing tests carried out in the laboratory which afford practical proof of the suitability of the atmosphere controlled furnace described in this article to harden both " 66 " and " 94 " substitute steels successfully. To quote Dr. Fells : " With a furnace temperature of 1,250° to 1,260° C., and a purging atmosphere practically the same as that used for an 18/4/1 tungsten high-speed steel, the steels have shown practically no scale after quenching in oil, no sweating nor fusion of scale, and no decarburisation. Hardness readings of 64–66 Rockwell are regularly obtained, and the fracture is good."

As a guide to the initial setting of the unburnt gas valves, the correct atmosphere is obtained when there is no orange or yellow in the flame visible at the peep-hole, with the furnace at 1,250°–1,260° C. Experiments with test-pieces will be necessary.

Further points have been revealed by Dr. Fells' tests on these steels. Firstly, the atmosphere is nothing like as critical as is generally thought, and good results can be obtained over a wide range of atmosphere settings. Secondly, the length of soaking time is very critical. Molybdenum steels have a marked tendency towards increase in grain size, and it is strongly recommended that the soaking periods for different sections are determined on test samples before any large heat-treatment of tools is carried out. Too long a soaking period, followed by oil quenching, may leave the steel austenitic and therefore show a low hardness reading ; it is also more likely to cause trouble than decarburisation due to an incorrect atmosphere setting.

The writer desires to express his thanks to the directors of Messrs. British Furnaces, Ltd., for permission to describe the above high-speed steel-hardening plant installed by their firm.

Recent Developments in Heat-Treatment

By A. G. Robiette, B.Sc.

Developments in heat-treatment, whether of methods or equipments, for metals and alloys, are only put into operation on a production basis after several years of experimentation and trial; thus the developments discussed by the author had their origin some years ago, but to-day they are being applied in an increasing measure to the special needs of war demands.

IT was fortunate that there was a considerable period of pre-war development in heat-treatment plant, and we have been able to reap the fruits of this development during the war period. In this time the mechanisation of furnaces was in a highly advanced stage, forced air circulation was almost universally adopted for the lower temperature treatments, and controlled atmospheres for annealing and hardening had become firmly established in many industries. These were all major developments, and it will probably be a long time before any further radical advancements will outstrip the progress made in the years immediately preceding the war.

In reviewing more recent developments in heat-treatment technique one cannot overlook certain major trends, and among these may be mentioned the wider use of air circulation employing higher air velocities by the use of "end flow" circulation. In the field of controlled atmospheres the treatment of tool steels, especially those containing molybdenum, has emphasised the need of scientifically controlled gas mixtures which cause neither oxidation nor decarburisation. Heat-treatment by induction for surface hardening, differential tempering, etc., has also increased in importance, and is becoming firmly established, especially in America. The development of suitable furnaces and atmospheres for gas carburising in this country is a definite step forward, whilst the production of cases containing both nitride and carbide by gaseous treatment is more than a possibility. Lastly, considerable progress has been made in gas-fired equipment, especially by the further use of radiant tube heating and by the close control of combustion mixtures so as to bright anneal non-ferrous metals without any externally applied atmosphere. The above are just broad indications of the lines along which progress has been made, and it will be of interest to pursue some of these in greater detail.

Forced air or atmosphere circulation considerably increases the convection component of heat transfer, thereby greatly augmenting the rate of heating up to temperatures of the order of 750° C. and with proper design eliminates inequalities of temperature. It was common to employ a multiplicity of fans in large furnaces to give the optimum forced convection effect. This, however, possessed a disadvantage of necessitating the division of the furnace into numerous separately controlled zones, and it possessed many disadvantages in the heat-treatment of long sections. More recently large fans located at the ends of the furnace force the air through the work chamber, which is virtually a wind tunnel and thence over the heating chamber, which is entirely separate and may be insulated from the work chamber. Higher air velocities are employed and increased temperature uniformity and higher speeds of heating are thus obtainable. Such a system has been employed on continuous as well as batch type furnaces with equal success. Fig. 1 is an illustration of such an "end flow" forced air circulation furnace for heating long sections, and a special quench tank is seen in the foreground.

In the treatment of tool steels, particularly with the advent of molybdenum-bearing high-speed steels, there has been a growing appreciation of the advantages of controlled atmospheres. The composition of the atmosphere is predetermined, and can be accurately maintained whilst the temperature is also under automatic control. This enables high-speed steel hardening to be done by diluted, and in many cases female, labour, with the results at least equal to those previously only attained with considerable skill. There is no difficulty in obtaining perfect hardening of form tools of any high-speed steel composition in furnaces of this type, since no final grinding to remove soft skin is necessary. Similarly, research on salts and improvements in salt-bath furnaces has made this type of plant equally

Fig. 1.—Birlec end-flow forced-air circulation furnace for the solution treatment of long aluminium alloy sections.

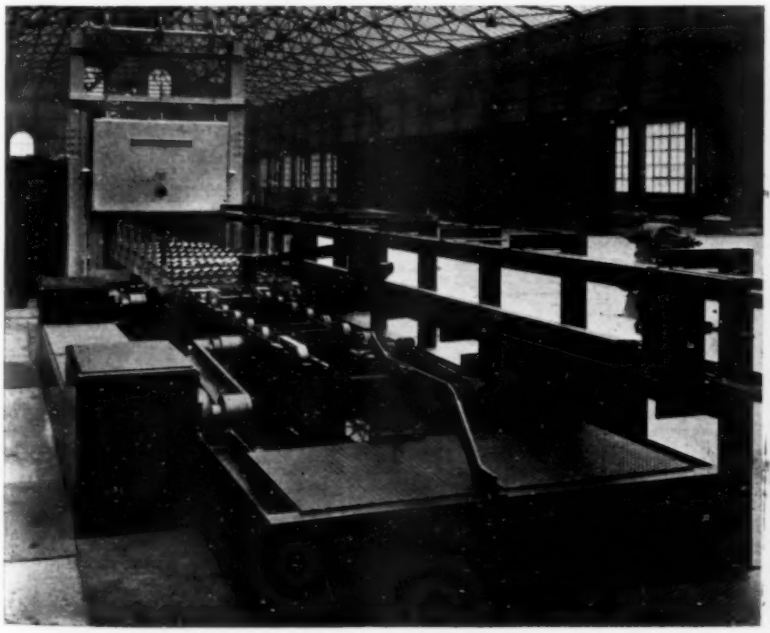
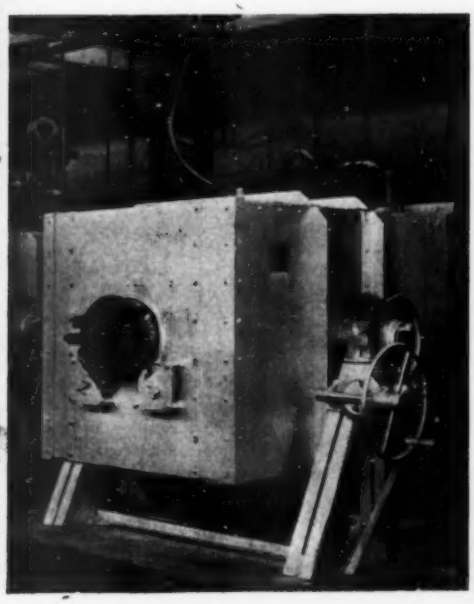


Fig. 2.—Birlec rotary gas-carburising furnace suitable for carburising small parts with either compound or gas.



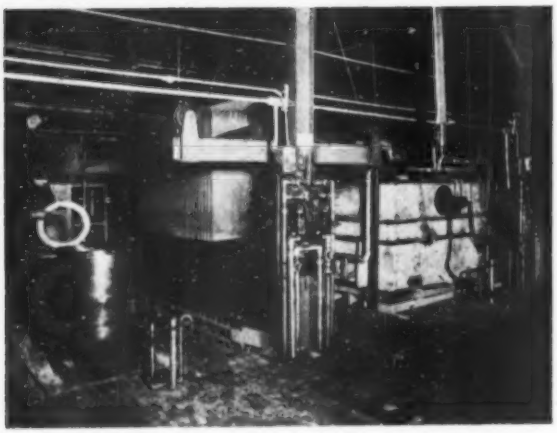


Fig. 3.—Birlec gas-fired bell furnaces for bright annealing mild and carbon steel strip.

suitable for these tool-treating operations. Another development in this connection is the use of the electrode type of salt bath for cyanide hardening. This has many operating advantages, such as a long pot life, elimination of gas fumes, and rapid and uniform heating.

The development of gas carburising has been particularly rapid in America during the past five or six years, where they are favoured by abundant natural sources of hydrocarbon gases and where large outputs of mass-produced parts lend themselves admirably to this process. In this country we were handicapped in both these directions, but research work in this field has enabled us to develop suitable gas mixtures relatively simply, and there is no reason why the cumbersome pack carburising methods, which are costly in both time and labour, should not be superseded for many purposes. Fig. 2 shows a rotary carburising furnace suitable for carburising small parts with either compound or gas, and can be arranged for direct quenching from the furnace. Gas carburising is suitable for operation in batch type or continuous furnaces, and it is certain that manufacturers will increasingly avail themselves of the advantages of this clean and convenient process.

The above remarks apply almost entirely to electrically heated furnaces, but the advances made in gas-fired equipment have in many directions been no less remarkable. These have taken the form of increased mechanisation, improvements in burner design, further progress in the application of radiant tubes, and the development of direct-fired bright annealing furnaces, with spray quenching.

The improved methods of mechanical handling so widely applied in electric furnaces have been assisted by the introduction of high chromium-nickel alloys, which resist creep and also are relatively immune from sulphur attack. This has eliminated the necessity for water-cooled rails and rollers, and for refractory topped beams.

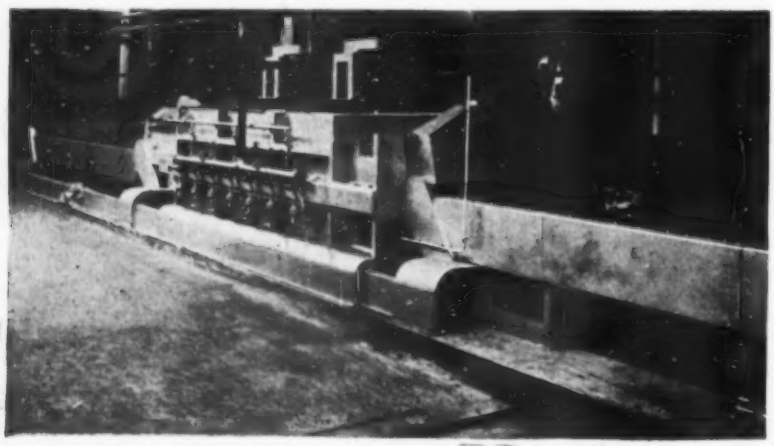
The increased efficiency of gas-fired furnaces obtained by the more liberal use of thermal insulation has introduced problems of burner design in connection with "turn-down" range. A thinly lagged furnace could operate satisfactorily with single-hole burners with a turn-down ratio of the order of 3 or 4 to 1, but a heavily lagged furnace may easily require a turn-down of 12 to 1. This has brought about the development of various designs of perforated tip burners, many of which are self-piloting and some are arranged for sparking plug ignition. Similarly, the same exigencies have brought about the introduction of the " throttling " type automatic temperature regulator which varies the supply of fuel according to the heat absorption capacity of the charge. For instance, the control allows a maximum gas flow when a cold charge is inserted, but when the desired control temperature is approached the gas supply is cut down or throttled to avoid overshooting.

The most outstanding type of burner of recent years is undoubtedly the radiant tube, which was developed to avoid contact of the products of combustion with the charge being treated. This type of burner gives conditions similar to those obtaining in any electric furnace. There have been further improvements in recent years in the making of these radiant tubes recuperative and employing sulphur-resisting cast alloys in their manufacture. In America a centrifugal casting is employed, and the life of the tubes has been considerably improved. Furnaces fired in this manner can be operated up to 1,050° C. for a variety of processes, such as vitreous enamelling, gas carburising, controlled atmosphere malleabilising, and in particular for clean hardening and bright annealing.

For bell type bright annealing furnaces the radiant tube has been used quite extensively, but there appears to be no reason to burn the gas in a tube in this case if the charge is already enclosed in a gas-tight cover. For this purpose the radiant tube has, in many cases, been superseded by what may be termed a " radiant block " burner of the open type. This burner is similar in form to the domestic bowl fire and a very large number of these flameless radiant units are suitably disposed over most of the wall surface. Fig. 3 illustrates a rectangular bell type furnace employing these burners for the bright annealing of coils and straight lengths of carbon and mild steel strip.

The other development in bright annealing, which is a noteworthy one, is in connection with non-ferrous materials. It is known that certain non-ferrous metals, such as copper and nickel, do not readily decompose water vapour or carbon dioxide. Theoretically, therefore, there is no reasou why a suitably designed direct gas-fired furnace should not be used for bright annealing copper, cupro-nickel and certain other non-ferrous products without any externally applied atmosphere. As the material has to be cooled in the same atmosphere to avoid oxidation, it is essential to quench the material from the furnace, and this is being done by very successful spray quenching equipment which is in use for sheets, tubes and other sections. Other problems which had to be solved on this type of furnace included the extremely accurate maintenance of the gas/air ratio to get the right composition of mixture containing no free oxygen and no excess of reducing gas, whilst it was essential to remove sulphur from the gas before combustion. A furnace designed on the above principles and installed for bright annealing copper, cupro-nickel and the clean annealing of brass is shown in Fig. 4.

Fig. 4.—Birlec gas-fired continuous furnace for bright annealing non-ferrous tubes.



The Prevention of Coarse-Grain Cracks in Tools Made with High-Tungsten and Substitute High-Speed Tool Steels

By D. W. Rudorff, A.Am.I.E.E., M.Inst.F.

The basic reason underlying the frequent cracking of milling cutters made from a number of high-speed steels has been investigated. The cracks experienced were of a nature pointing to the occurrence of grain-coarsening, although, apparently, specified hardening temperatures had been adhered to. It is shown that coarse-grain cracks can occur in all high-speed steels when normal heating time and quenching temperature are exceeded.

TO-DAY more importance than ever attaches to the choice of proper hardening conditions in the manufacture of cutting tools made with standard or "substitute" high-speed steels. A review of a recent investigation concerned with the hardening of milling cutters should therefore be particularly timely. This investigation* was sponsored by an important Czechoslovakian steel-maker† in order to ascertain the basic reason underlying the frequent cracking of milling cutters made with high-speed tool steel of his make. Unlike ordinary quenching cracks, caused by uneven or unduly fast heating, the fissures experienced in this case were of a nature pointing to the occurrence of grain-coarsening, and this in spite of the fact that to all appearances, specified hardening temperatures had been adhered to. As the beginning of the trouble happened to coincide with the introduction of substitute steels with lowered tungsten content, it was natural to assume that the cause of the frequent failures had to be looked for in a particularly pronounced sensitivity of the substitute steels to overheating. A statistical survey, however, brought to light the fact that the manufacture of milling cutters with 18% W steel and 18% W, 5% Co steel was similarly affected. A systematic study of the hardening procedure was therefore considered essential in order to find the cause of the trouble and its remedy.

In recent years, the electrically heated salt bath has been steadily gaining ground as a convenient and reliable means of effecting heating of the tool to be hardened to proper temperature of quench; the bath temperature being chosen in accordance with the requirements of the individual case. With regard to milling cutters, it can be said that in general the proper bath and hardening temperature will lie in the range between 1,150°–1,300° C., while the temperature must be chosen according to the type of steel used, size and shape of the tool to be hardened, etc. Once the correct temperature of quench has been determined, measures must be taken to ensure maintenance of this temperature with an accuracy of + 10° C.

In view of the great importance attached to the maintenance of proper salt-bath temperature, preheating of the tools prior to their immersion in the salt bath is essential. Generally, preheating temperatures of at least 850°–950° C. will be chosen. Preheating is either carried out in a salt bath (usually in two stages) or in gas, oil or electrically heated furnaces. When employing a furnace, certain tools are preferably packed in granulated burnt coke in order to protect their surfaces against decarburisation and scaling. When preheating is carried out with the use of a salt bath, care must likewise be taken to avoid a deterioration of the tool surface by decarburisation.

Quenching of the tools in the course of the investigation referred to was carried out in oil, air blast, or in salt baths. The experiences made with the employment of the various heating methods in connection with the hardening of substitute steels, are claimed to have conclusively proven that no substance whatsoever attaches to the claim that the greater temperature sensitivity of these steels makes the employment of salt baths imperative.

The actual cause of the frequent occurrence of coarse-grain cracks was ultimately found to lie in an excessive temperature of the salt baths (consisting of barium chloride with an addition of borax) originating in faulty temperature measurement. But the situation was considered serious enough to warrant a detailed investigation of the tendency of the various steels employed to develop coarse-grain cracks in the event of excessive bath temperature. For this purpose, sample pieces measuring 47 mm. in diameter and 50 mm. in thickness were made with the following steels :—

Steel No.	C, %	Cr, %	Mo, %	V, %	W, %	Hardening Temperature, °C.
1	0·75	4·5	0·6	1·5	1·0	1220–1250
2	0·95	4·5	2·4	2·8	2·5	1200–1230
3	1.3	5·0	1·0	4·0	12	1220–1250
4	0·75	4·5	0·7	1·5	18	1260–1290
5	0·75	4·5	0·7	1·5	18*	1260–1290

* + 5% Co.

Unlike the actual milling cutters, which these pieces were meant to resemble, all test-pieces were left without the central bore. This omission was made in order to prevent the equalisation or diminution of internal hardening stresses. The various methods employed in the heating for quench as well as the various quenching media employed are shown in the subjoined Tables I and II. All pieces were preheated to about 850° C. in a gas-fired furnace for about 1 hour, while tempering was done at 560° C. in an electric furnace of the forced convection type. The whole hardening and tempering process took about 2 hours per piece. With regard to the tests in which heating was effected in the oil-fired furnace, it should be noted that after preheating the hot pieces were packed in metal containers filled with burnt coke, and then brought to final temperature in the oil-fired furnace. As the tables show, two test series of this kind were undertaken, the heating run in one case lasting the normal length of time of 35 mins., and the other for 65 mins. After hardening and tempering, the pieces were carefully cleaned and examined for cracks. After a few weeks this examination was repeated.

Tables I and II are seen to emphasise the importance attached to the choice of proper time of immersion in the salt bath. According to the original report, the correct immersion times to be employed under the prevailing conditions were found to be the following :—Steel (1) and steel (3), about 2¾ mins.; steel (2), about 2½ mins.; while the high-tungsten steels (4) and (5) required approximately 3 mins. The fact that in the case of excessive heating temperature, the consequences of overheating are largely determined by the time element, was fully confirmed by the result of the examination of three test-pieces of steel No. 3. In this case, no cracks were observed in a piece quenched

† Poldihuette.

* O. Pattermann. *Stahl und Eisen*, December 25, 1941, p. 116.

from 1,240° C. after holding it at this temperature for 3 mins.; but cracks did occur in another piece quenched from the identical temperature after having been held at this temperature for 6 mins. Cracks were likewise observed in the third piece hardened from 1,280° C. after having been held at this temperature for 6 mins.

TABLE I.

Quenching temperature, ° C.		Steel 3.				Steel 4.				Steel 5.			
		1,240.		1,280.		1,280.		1,320.		1,280.		1,320.	
Heating Time in Salt Bath, Mins.	Quenching Medium.	Rc.	Cracks.	Rc.	Cracks.	Rc.	Cracks.	Rc.	Cracks.	Rc.	Cracks.	Rc.	Cracks.
3	Oil of 25° C.	65	†	65	†	64	†	65	†	64·5	†	64·5	†
3	Oil of 100° C.	65·5	†	65	†	64·5	†	65	†	65	†	64·5	†
6	Oil of 25° C.	65	*	65	*	65	*	64·5	*	65	†	64·5	†
6	Oil of 100° C.	65	†	65	*	65	*	65	*	65	†	65	*

* Cracked. † Not cracked.

Examination of the microstructure showed the following inter-relationship between hardening temperature and grain size. In the case of the substitute steel (1), satisfactory structure was obtained when quenching from 1,250° C. after 3 mins. immersion in the salt bath, while polyhedral structure was exhibited by a piece quenched from 1,280° C. This temperature must therefore be considered as somewhat too high for the hardening of milling cutters. A third piece, quenched from 1,320° C., showed newly formed ledeburite indicating pronounced grain coarsening. When quenching from 1,250° C. after 6 mins. immersion in the salt bath, the formation of polyhedral structure became quite noticeable. Polyhedral formation became still more pronounced with a piece quenched from the same temperature after 10 mins. immersion, and in this case ledeburite formation in some spots could also be found.

In the case of substitute steel (2), quenching from 1,200° C. after 3 mins. immersion in the salt bath yielded the degree of hardness desired in milling cutters, only few secondary carbides remaining undissolved. Quenching from 1,240° C. likewise resulted in satisfactory hardening without grain-coarsening. However, pieces hardened from 1,280° C., showed distinctly acicular structure without exhibiting polyhedral boundaries in the tempered structure. While in a piece hardened from 1,240° C. after 6 mins. immersion in the salt bath, polyhedral structure could hardly be noticed, this became rather pronounced when quenching from the same temperature after 10 mins. immersion. It was, however, much less pronounced than that observed in a piece of substitute steel (1) quenched from 1250° C. after 10 mins. immersion.

TABLE II.

Quenching temperature, ° C.			Steel 1.						Steel 2.					
			1,250		1,280		1,320		1,200		1,240		1,280	
Heating Means.	Heating Time. Mins.	Quenching Medium.	Rc.	Cracks.	Rc.	Cracks.	Rc.	Cracks	Rc.	Cracks.	Rc.	Cracks.	Rc.	Crack
Salt Bath.	3	Oil of 25° C.	65	†	65	†*	64·5	*	64	†	64	†	64·5	†
		Oil of 100° C.	64·5	†	65	†	64·5	*	64·5	†	6.·5	†	64	*
		S. bath of 350° C.	65	†	65	†	65	*	64	†	65	†	64	*
		S. bath of 550° C.	64·5	†	64	†	64	†	64	†	64	†	64·5	*
		Air blast	64·5	†	64	†	64	†	64	†	64	*	65	*
	6	Oil of 25° C.	65·5	†*	64·5	*	65	*	64	†	64	*	65	*
		Oil of 100° C.	65	†	64·5	*	64·5	*	64	†	64	*	64·5	*
		S. bath of 350° C.	65	†*	64·5	*	64·5	*	64	†	64	*	64·5	*
		S. bath of 550° C.	64	†	64	†	64	†	64	†	64·5	†	64	*
		Air blast....	64·5	†	65	†	65	†	64	†	64	†	60	†
	10	Oil of 25° C.	65	*	64·5	*	64·5	*	64	†	64	*	65	*
		Oil of 100° C.	65	*	65	*	64·5	*	64	†	64·5	*	65	*
		S. bath of 350° C.	64·5	*	64	*	64	*	64	†	64	*	65	*
		S. bath of 550° C.	64·5	†	64·5	†	64	†*	63·5	†	63·5	*	64	*
		Air blast	65	†	64·5	†	64·5	†	62	†	61	†	59	†
Oil-fired Furnace Coke Packing.	35 (normal)	Oil of 25° C.	65	*	—	—	—	—	64	†	64·5	†	65	†
		Oil of 1.0° C.	65	†	—	—	—	—	64·5	†	65	†	64·5	†
		S. bath of 350° C.	64·5	†	—	—	—	—	64	†	64	†	64·5	†
		S. bath of 550° C.	65	†	—	—	—	—	64·5	†	65	†	65	†
		Air blast	65	†	—	—	—	—	64	†	64	†	64	†
	65 (prolonged)	Oil of 25° C.	65	*	—	—	—	—	65	†	65	†	64·5	*
		Oil of 100° C.	65·5	*	—	—	—	—	64·5	†	65	†	64·5	*
		S. bath of 350° C.	65	*	—	—	—	—	65	†	64·5	†	64·5	*
		S. bath of 550° C.	64·5	†	—	—	—	—	64	†	64	†	64	*
		Air Blast	65	†	—	—	—	—	65	†	64·5	†	64	*

† Not Cracked. * Cracked.

In the case of steel (3), the correct amount of hardening required in milling cutters was found to obtain when quenching the piece from 1,240° C. after 3 mins. immersion, the structure exhibiting the very beginning of acicular formation. (The latter becomes plainly visible when quenching from 1,280° C.) In a piece quenched from 1,240° C. after 6 mins. immersion, grain coarsening became quite evident. With 1,280° C. and 6 mins. immersion, polyhedral formation became very noticeable, and small traces of ledeburite formation could also be found.

When investigating the high-tungsten steel (4), quenching from 1,280° C. after 3 mins. immersion gave the desired degree of hardness, while the employment of a hardening temperature of 1,320° C. led to the development of polyhedral formation, signifying an unduly high hardening temperature for milling cutters. An immersion time of 6 mins. when hardening from 1,280° C. gave full hardening, with a beginning of acicular formation. The combination of an immersion time of 6 mins. with a quenching temperature of 1,320° C., resulted in the production of pronounced grain coarsening. As regards the characteristics displayed by steel (5), it is sufficient to say that these were found to be almost identical with those established for steel (4).

From these results it can be concluded that with regard to the grain coarsening effect produced by an extension in immersion time from 3 to 6 mins., this is equivalent to an increase in hardening temperature by 25° C. in the case of steels (1) and (2), and of 30° C. in the case of the other steels investigated. As regards an extension of immersion time from 3 to 10 mins., its grain coarsening effect in the case of steel (1) can be considered to be equivalent to an increase in the hardening temperature by 30° C., and by 35° C. in the case of steel (2).

On the average, all pieces investigated showed a normal hardness of 64–65·5 Rc. However, air-quenched samples of steel (2), hardened under conditions of abnormally high temperature and excessively long immersion time, showed somewhat lower hardness. This may have been due to a retardation in quenching speed owing to the formation of an insulating salt coating on the surface of the pieces. As the original report points out, neither surface carburisation nor decarburisation could be observed. Pieces not fully hardened, were found to lose in hardness after tempering at 560° C.

With regard to the occurrence of coarse-grain cracks, the following observations were made: While the correct hardening conditions for pieces made with steel (1) were found to lie in a temperature range of 1,220°–1,250° C. with an immersion time in the salt bath of $2\frac{3}{4}$ mins., crack-free pieces could still be obtained with 1,250° C. and 3 mins. immersion time. When quenching from 1,280°, only one sample quenched in cold oil was found to exhibit coarse-grain

cracks. In the case of the pieces of steel (1) quenched from 1,320° C., only those quenched in oil or in an insufficiently hot salt bath were found to show cracks. Hardly any danger of cracking will therefore be incurred when hardening this steel at the hardening temperature of 1,260°–1,290° C. specified for the high-tungsten steel (4), provided of course that the heating time in the salt bath is kept within reasonable limits and that the quench is not too abrupt. With an extension of immersion time to 6 mins. or even 10 mins., the danger of cracking is naturally increased, but for coarse-grain cracking to take place with excessive heating and excessive length of immersion, a rapid quench is also required. However, with milling cutters and similar fine-cutting tools, a fine structure is a prime necessity ; therefore hardening temperature and immersion time must be so chosen that they do not fall into the zone in which grain-coarsening is likely to occur.

The results obtained with the hardening of the pieces heated in packed state are also interesting. Of all test-pieces heated and soaked at 1,250° C. for 35 mins., only those quenched in cold oil were found to have developed cracks. Also, of the pieces soaked for 65 mins. at the same temperature, only one of those subjected to very rapid quenching was found to have cracked. Among the various quenching methods tried, air-blast and hot-bath quenching proved to be perfectly safe even in cases where grain coarsening had taken place. But this observation solely applies to the samples tested, and in the hardening of complicated pieces exhibiting grain coarsening, cracking will not be obviated by the employment of a mild quench. This danger is illustrated by the cracking of one of the sample pieces when quenched in the 550° C. salt bath after heating to 1,320° C. for 10 mins.

When hardening the pieces made with the substitute steel (2) by quenching from 1,200°–1,250° C. after heating for 2½ mins., not one case of cracking occurred. Nor did any cracks develop when a piece heated for 3 mins. was quenched from 1,240° C. in cold oil. This and similar experiences obtained with steel (1) go to show that no objection exists against heating of the pieces of substitute steel in packed state. It is interesting to note that pieces of steel (1) and (2) heated in packed state and quenched at the specified respective temperatures, exhibited structural characteristics very similar to those found in samples subjected to a corresponding treatment with the use of the salt bath.

The structure formation and tendency to crack exhibited by pieces which had been heated for an excessive length of time in packed condition (65 mins. instead of 35 mins.) was not found inferior to that obtained with pieces which had been immersed in the salt bath for 10 mins. instead of for 3 mins. The only exception in this respect was experienced with the air-blast hardening of pieces of steel (2) at 1,280° C. In this case, a piece immersed in the salt bath for 10 mins. did not develop cracks, while the piece heated in packed state for 65 mins. was found to crack when quenched by air-blast. But this is hardly of any import, since a milling cutter subjected to such a mistreatment would in any event show unsatisfactory cutting properties and service life.

Pieces made with the substitute steel (3) showed no cracks when hardened from a temperature exceeding the specified maximum. But cracking did occur when normal hardening temperature was combined with excessive heating time, and the piece was quenched in cold oil. The same occurred with a piece subjected to both unduly high hardening temperature and unduly long heating time. Another similar piece was also found to crack when quenched in hot oil. In general, it was, however, found that the limit hardening temperature and heating time specified for this very hard high-speed steel are as acceptable as those specified for steels (1) and (2).

Considering the fact that pieces of the high-tungsten steel (4) were found to develop cracks with both hot and cold oil quench, when the proper heating time was exceeded, while keeping the hardening temperature at normal, this steel can by no means be considered to possess greater resistance to grain coarsening than the substitute steel (3). Only the cobalt steel (5) appears to be slightly superior in this respect. With this material both hardening temperature and heating time must be exceeded in order to produce coarse grain cracks, while doubling of the heating time alone from 3 to 6 mins. did not produce cracks. As the original report states, these laboratory figures were fully borne out by shop experiences.

The knowledge gained from this investigation can be summarised thus : Coarse-grain cracks can occur in all high-speed steels when normal heating-time and quenching temperature are exceeded to such an extent as to produce grain coarsening. And this applies to both salt bath and furnace heating. The danger of cracking is increased by rapid quenching. The most effective method available for obviating the occurrence of coarse-grain cracks is the employment of air-blast quenching or of high temperature salt-bath quenching. Quenching in a salt bath of comparatively low temperature is just as dangerous as a cold oil quench.

Substitute steels containing ca. 10% W and 1·5% V, or 2·4% Mo, 2·8% V, and 2·5% W, or also 12% W and 4% V, possess a reasonable margin of safety against grain coarsening.

The steel containing 2·4% Mo, 2·8% V and 2·3% W attains full hardness at low hardening temperature, and possess a satisfactory degree of safety against grain coarsening both as regards hardening temperature and length of heating. Even with considerable excess in heating temperature and heating time, grain coarsening and ledeburite formation remain within tolerable limits.

No differences in the surface quality of the various steels could be noticed ; the substitute steels are not herefore inferior as regards decarburisation, carburisation, or corrosion, provided, of course, the specified heating and quenching temperature ranges are adhered to. But it must be kept in mind that the hardening temperature range of the substitute steels is lower than that of the high-tungsten steels. In the opinion of the investigator, the comparatively low temperature range which must be adhered to in the case of the substitute steels should be considered an advantage rather than a disadvantage. The difficulty of keeping the tool surface free from damage increases sharply with the temperature ; and a decrease by 30°–50° C. in the hardening temperature must therefore be considered an important advantage. Correct measurement of the hardening temperature is of course of paramount importance.

As a rule, salt-bath temperatures are determined with the use of total radiation pyrometers. In this connection a thorough removal of salt vapours is quite essential in order to avoid very considerable errors in temperature measurement. Vapour formation is especially pronounced in cases where preheating of the tools is effected in special preheating salt baths. This is due to the fact that transfer of the tool from the preheating to the final salt bath is accompanied by a certain carry-over of salt adhering to the tool. When introduced into the final bath, this salt, which possesses a lower melting and vapourising temperature, evaporates with great rapidity. Experience has shown that during one day's operation the small amounts of salt transferred in this way may be able to effect a considerable deterioration in the accuracy of temperature measurement, in some cases depressing the pyrometer reading by as much as 50° C.

Further to a war emergency schedule of steels issued in 1941, a supplementary memorandum has been published by the British Standards Institution which gives particulars of directions issued by the Ministry of Supply, to alloy steel ingot makers, with a view to economising in the use of alloy elements. It is publication 970A–1942.

Some Recent Heat-Treatment Furnace Installations and Equipment

By William Ashcroft

There are no fixed standards to determine definitely the proper form of heating and cooling equipment or the form of fuel or electricity to be used. Each must be considered with reference to the other and the suitability of the combination to the heat-treating process and operating conditions as a whole, but recent installations, some of which are briefly discussed, indicate development trends.

THE need for correct heat-treatment to bring out the properties most desired in a material has assumed greater importance in the present emergency. Apart from the fact that the heavy conditions to which many materials are subjected in war service, the efforts to conserve alloying metals are resulting in a more careful grading of the materials to prevent an excessive use of the alloying metals; it is necessary, therefore, that components be properly heat-treated to produce the require properties in the material used. Developments in the design and construction of suitable plant, and in its equipment, are contributing to the success achieved, but furnaces should be regarded more or less as precision tools which need skill and judgment on the part of the operator.

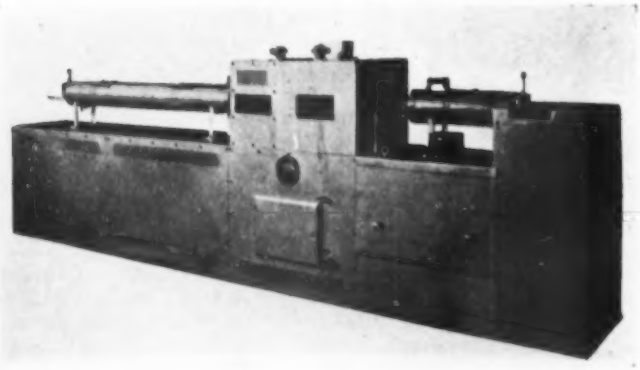
In the present emergency designers and manufacturers of heat-treatment furnaces have concentrated on the problems associated with war production needs, and many fine plants have been installed for specific purposes that embrace many new features, some of which are referred to elsewhere in this issue; in the main, however, standard types of furnaces have been in greater demand, though in many cases slight modifications have been made to meet particular requirements. In view of the conditions prevailing, it is only possible to refer briefly to a few recent installations, but they do indicate, in a measure, the upward trend in the design of furnaces and their equipment.

General standardisation of small furnaces of certain types has been recognised for many years, and it is being increasingly applied to controlled atmosphere furnaces. Thus, in Fig. 1 is depicted a standard design of atmosphere controlled furnace which is used in this case for bright brazing. This furnace embraces a continuous equipment consisting of a straightforward simple pusher mechanism. The furnace proper comprises a short water-cooled entry duct connected at one end to a gas-tight retort of 3½ in. × 1½ in. cross-section, which passes through the furnace chamber and connects to the water-cooled cooling chamber. The furnace chamber proper is in two zones, the first or preheating zone being of muffle construction, followed by the high-temperature zone. The control equipment comprises a single indicating automatic temperature controller embodying a variometer unit and full switch gear and transformer, with tappings to feed the high-temperature elements at reduced voltage. With the exception of the automatic temperature controller, this equipment is a self-contained unit, the switchgear, transformer, and all the pusher mechanism being mounted upon the stand and protected by guards. The atmosphere in this case is produced from one of the furnace manufacturer's own town's gas-burners.

A departure from standard practice is indicated by Fig. 2, which shows the furnace portion only of a bright annealing installation for dealing with 97–3 copper-zinc and 80–20 copper-nickel strip. A number of these furnaces have been installed, and one of the interesting features is the special vertical design which reduces to a minimum the floor space required; built on the more orthodox horizontal lines, the floor space occupied by these furnaces would be very large, and constitutes a problem when many

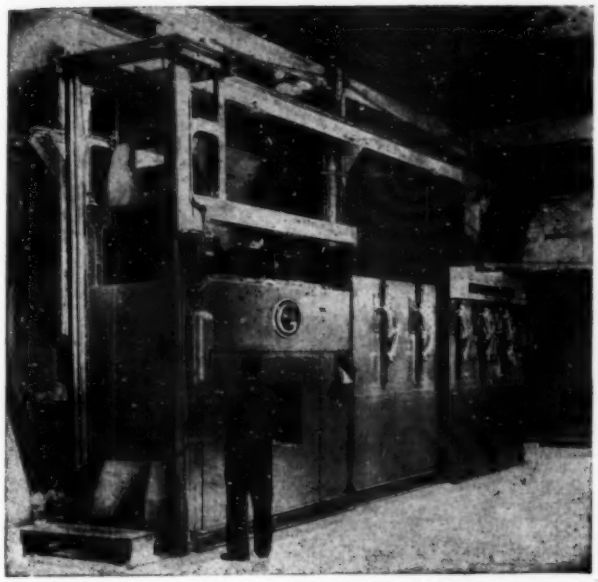
Fig. 1.—An atmosphere controlled furnace with continuous equipment, comprising a pusher mechanism.

Courtesy of Wild Barfield Electric Furnaces, Ltd.



Courtesy of Wild Barfield Electric Furnaces, Ltd.

Fig. 2.—Bright annealing furnace for treating copper-zinc and copper-nickel strip. Note the special vertical design.



Courtesy of G.W.B. Electric Furnaces, Ltd.

Fig. 3.—A reciprocating tray furnace with recuperation, known as the recuperative "Shaker" furnace.

are required. It is noteworthy that, being of vertical construction, the equipment as a whole forms a perfect gas-lock.

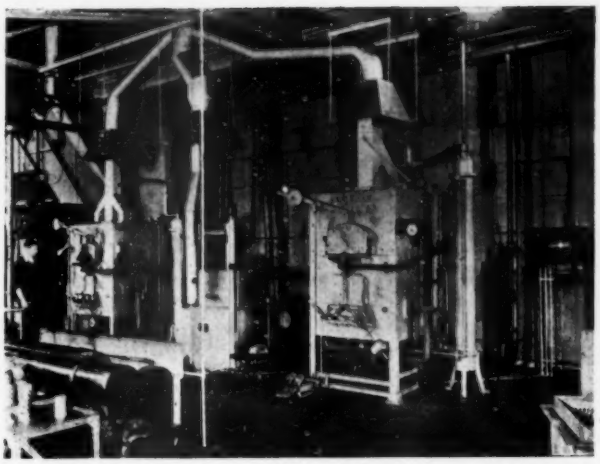
The design of this furnace follows normal lines. It is approximately 5 ft. 8 in. long, having a maximum operating temperature of 900° C., and divided into three independently controlled temperature zones. A gas-tight retort is provided inside the furnace chamber, which is extended at the exit to connect with the cooler. The cooler is actually in two sections, a short length immediately following the furnace chamber leading to the gas chamber at the top of the furnace, and a longer chamber reaching from the top to the base of the equipment.

As will be noted in the illustration, the strip passes over a roller at the base of the furnace, travels up through the furnace chamber and the short cooler to a further roller, from whence it passes to the winding gear.

Each installation is complete with its own coiling and uncoiling gear and full electrical ancillary equipment. The latter comprises three separate automatic temperature controllers for controlling the temperature in each zone, a transformer to feed the elements at reduced voltage and switchgear. A spot-welder is also included with each furnace, to join the ends of the coils of strip. The total rating of the furnace is 15 kw., and the output 2¼ cwts. of strip per hour at 670° C. The average speed of strip through the furnace is 5½ ft. per min., though this is variable from 4–8 ft. per min. A protective atmosphere is obtained from an I.C.I. straight ammonia burner with a 5 cub. metre cracker unit.

General standardisation of large electric furnaces is difficult in view of the rapid and ever-increasing change in heat-treatment specifications, but there are certain types of continuous furnaces in which the means of conveying has remained the same for many years without, it would seem, any serious attempt by the designer to secure increased efficiency. The reciprocating tray furnace with recuperation, shown in Fig. 3, however, represents a definite advance in this direction, and has aroused considerable interest among manufacturers of small and medium-sized brass pressings and light components. Mass productive heat-treatment is essential in such work, and the initial work for war purposes has greatly increased its interest.

This furnace, known as the recuperative "Shaker" furnace, includes automatic feeding and pickling equipment. The principle employed for conveying the charge on a level tray is the adoption of the principle of the parallel



Courtesy of Brayshaw Furnaces and Tools, Ltd

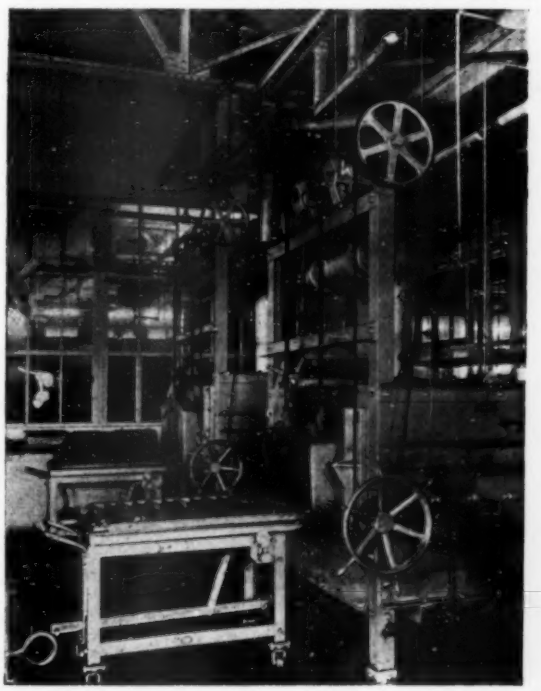
Fig. 4.—Controlled atmosphere furnaces for the heat-treatment of high-speed steels.

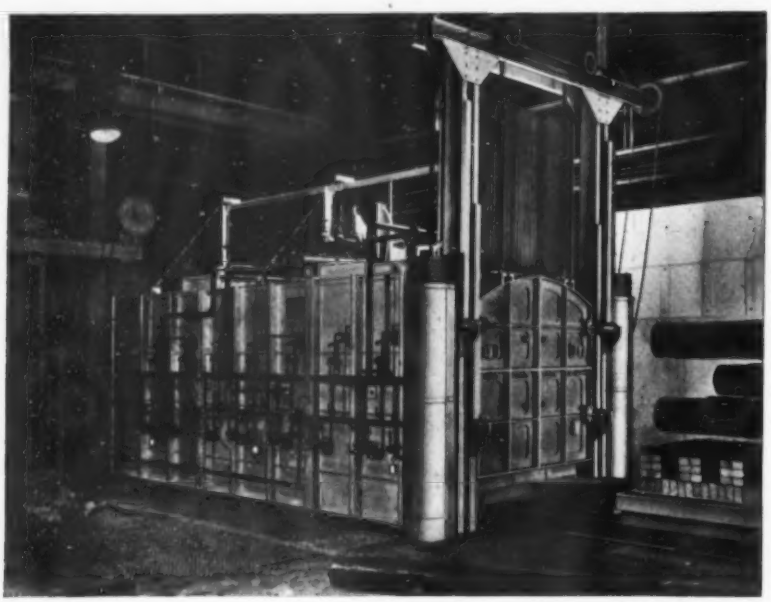
link motion. The method of conveying the charge is accomplished by transferring the oscillating movement of a crank to the furnace tray. In practically all respects the "Shaker" furnace fulfills the essential requirements for a uniform, consistent and cheap method of heating, and it is installed for numerous applications.

Recently a large engineering firm located in the Midlands renewed the entire plant in their heat-treatment department. Part of this plant is shown in Figs. 4 and 5. The former shows controlled atmosphere furnaces manufactured under licence from the Sheffield Gas Co.'s patents. Each furnace has its own combustion chamber and cooler to provide the necessary products for the balanced inert atmosphere, giving practically scale-free hardening conditions. This type of furnace is particularly suitable for the hardening of the "Substitute" high-speed steels. The salt-bath furnace, shown between the two controlled atmosphere furnaces, is used for secondary hardening and tempering processes. The quenching tank, which is alongside, is fitted

Fig. 5.—Two carburising furnaces equipment with load table. Note roller chain operated door gear.

Courtesy of Brayshaw Furnaces and Tools, Ltd.





Courtesy of British Furnaces, Ltd.

Fig. 6.—One of two large car-bottom furnaces, for annealing, hardening or tempering. The bogie is 6 ft. wide and 24 ft. long.

with an ingeniously arranged hood to protect the operator when the charge is quenched.

Arranged in front of the atmosphere controlled furnaces is a cooling table for air-cooling high-speed and carbon steel tools after hardening. The tools are placed on revolving tables which ensures uniform cooling. A stationary table for special work is also available. Each table has its own air supply, with a damper control to regulate the flow of air.

Fig. 5 shows two of the carburising furnaces with loading tables. Note the roller chain operated door gear, which gives very easy door operation. The loading tables are provided with a toggle mechanism which permits the tables to be raised or lowered when loading or unloading the carburising boxes.

One of two large car-bottom furnaces recently installed in one of the Royal Ordnance Factories is shown in Fig. 6. These furnaces are designed for annealing, hardening, and tempering processes, and have a range in temperature control from about 400° to 1,100° C., and the uniformity of heating is such that recent orders have been received for two slightly smaller furnaces of similar type. The furnace illustrated has a bogie 6 ft. wide and 24 ft. long, and it is capable of taking charges weighing up to 60 tons. It is a single-ended furnace, with a counterbalanced hand-operated door, and the bogie is operated in and out of the furnace by means of an electric winch. Firing is carried out by automatic proportioning single-valve control gas-burner equipment.

Several large furnaces for the solution heat-treatment of aluminium alloys have been installed by G.W.B. Electric Furnaces, Ltd. In one case the furnaces are of the pusher type, with heating chambers 32 ft. 6 in. long and 6 ft. 6 in. wide, and 1 ft. 8 in. high, and complete with all quench gear and tanks. In other cases the furnaces are of the well-known tubular design, with the quench gear arranged in line with the furnaces. The charge is contained in a suitable skip running on idler rollers in the furnace and on the quenching gear platform. All gear is electrically operated, and the full skip can be withdrawn from the furnace and quenched in 15 secs.

An installation of solution treatment and annealing furnaces, employed in the production of Duralumin tubes of varying sizes and gauges, is shown in Fig. 7. The furnaces are designed to accommodate tubes having a maximum length of 18 ft. 6 in. Each furnace is identical in design, being divided into three separately controlled zones of heating, and provided with four circulation fans. The three furnaces are fed from a common charging machine and each furnace has a connected load of 110 kw. In the case of the solution treatment furnace, on the left of the illustration, a charge is first loaded on to the quench-tank platform, then into the furnace by the quench-tank traversing gear. This traversing gear is designed to withdraw a charge and quench it within a maximum of 30 secs.; in practice the usual time is 20 secs.

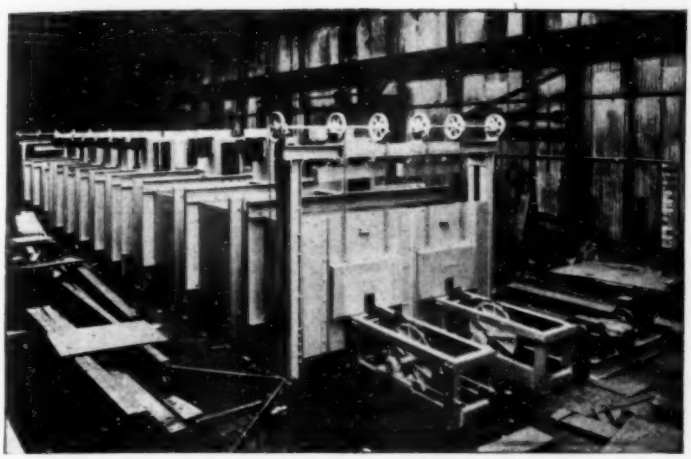
Fig. 8 is noteworthy in that it illustrates a furnace which was recently shipped overseas. This furnace is of the recuperative type, employing continuous chain mechanism for traversing suitably designed trays mounted on idler roller track through the furnace. This installation is designed with two separately controlled chambers, with recuperative chambers at each end, and by having the conveyer chains moving in opposite directions, recuperation is provided at either end. High-power air-circulation fans are provided both in the heating and recuperative chambers to allow for the maximum of recuperation. The connected load on each chamber is 180 kw., divided into three separately controlled zones of heating, making a total of 360 kw. for the two furnace chambers.

Mention may be made here of a rather novel electric furnace for the heating of the ends of rods, tubes and long bolts. The work passes continuously through the furnace, which despite its small size has quite a large output. The furnace illustrated in Fig. 9 serves for softening the ends of 15 in. × ⅝ in. o.d. alloy steel tubes at a temperature of 750° C., the output being approximately 20,000 tubes per 50-hour week. The tubes lie side by side on a platform, with their ends projecting into the slot along the front of the furnace. Beyond the right-hand end of the furnace the platform is inclined and serves as a self-propelling magazine for the incoming tubes. Every 10 secs. the operator withdraws one tube from the left-hand end of the furnace. As each tube is withdrawn all the remaining tubes on the platform and magazine move along under gravity to fill the empty space. There is no mechanism.

An interesting range of Leeds and Northrup electric heat-treatment furnaces is manufactured under licence by the Integra Co., Ltd. A recent addition to this range is the "Homocarb" carburising furnace, which is of the vertical cylindrical type, much the same design as the "Homo"

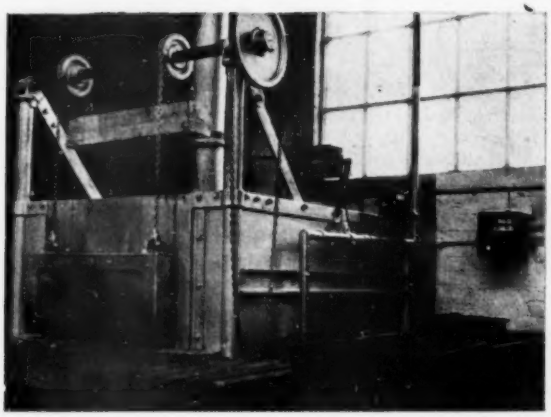
Fig. 7.—An installation of solution and annealing furnaces for the production of Duralumin tubes up to 18 ft. 6 in. long and of varying sizes and gauges.

Courtesy of Metalectric Furnaces, Ltd.



Courtesy of Metalectric Furnaces, Ltd.

Fig. 8.—A recuperative type electric furnace, employing continuous chain mechanism for traversing suitably designed trays carrying the charge.



Courtesy of Ether, Ltd.

Fig. 10.—Furnace for heat-treatment of air-cooled cylinder blocks fitted with indicating temperature controller, solenoid operated gas valve, and motor-driven damper unit.

nitriding furnaces, but with heating elements for temperatures up to 1,000° C. and equipped with a gas-tight retort used in conjunction with the " Homocarb " fluid, which is injected into the furnace by a small pump. This fluid impinges on a target attached to the lid, which causes it to crack into a rich carburising atmosphere to be circulated throughout the charge by a fan. This equipment has the advantage of cleanliness, faster rate of carburising, and the elimination of the lengthy packing necessary in box carburising.

Temperature Control Equipment

The problem of control in its application to heat-treatment is a complex one, and involves many factors, notably control of the rate and time of heating and cooling of the components being treated, and it should not be assumed that furnace temperature control is sufficient evidence in itself that the component is uniformly heated to the required temperature. Uniform heat-treatment however, is achieved more easily by careful control of the various operations involved, and equipment for the measurement and control of heat in the furnaces contribute greatly to the success of the process. Reliable instruments for securing, maintaining, and recording a constant temperature, with facilities for working to a pre-arranged time temperature scale are available, and their use has become essential in modern heat-treatment operations.

The use of temperature indicating and controller instruments is well known, but a brief reference to some applications may be made. Thus, Fig. 10 shows a furnace used for the heat-treatment of air-cooled cylinder blocks, fitted with an indicating controller together with a solenoid operated gas valve and motor-driven damper unit. There are many types of temperature indicators, each covering a range of temperature and arranged either for single-point readings or as multiple types to which a number of furnaces may be connected. The furnace installation may be fitted with a continuous indicating and recording instrument as one unit, while further progress in the instrumentisation of heat-treatment furnaces is the programme regulator, a motor-driven means of controlling any type of heat-treatment furnace to a predetermined time-temperature cycle. The Electroflo time cycle or programme regulator, for instance, in conjunction with reliable temperature control instruments, will provide control to any desired time-temperature cycle extending over a few minutes or over several days. Many of these instruments are in use on large, long period normalising, and other heat-treatment furnaces; mention may be made of an installation of 12 such control panels used in conjunction with automatic stokers for heating the furnaces. Extremely fine control is obtained by regulation of the stoker motor, or, if a gearbox is fitted, varying speeds can be selected automatically to suit the exact furnace conditions.

An installation of this kind ensures the maximum adherence to any desired time-temperature cycle, and, what is perhaps equally important in these days, the whole cycle is followed automatically without attention from furnace operating staff. It will be obvious that a large battery of furnaces can be operated by a few men only, as all their time can be devoted to charging and discharging the furnaces, since they are not concerned with the continual regulation of furnace dampers, gas cocks, oil-burner valves, etc.

Fig. 9.—Novel electric furnace for heating the ends of rods, tubes, and long bolts.

Courtesy of Siemens Schuckert (Gt. Britain), Ltd.

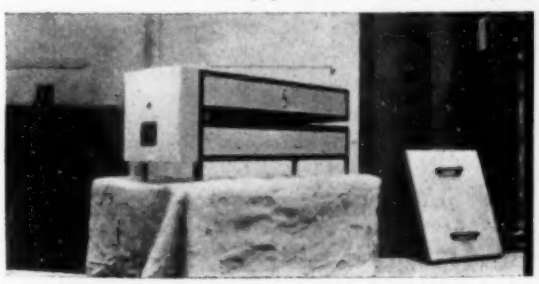
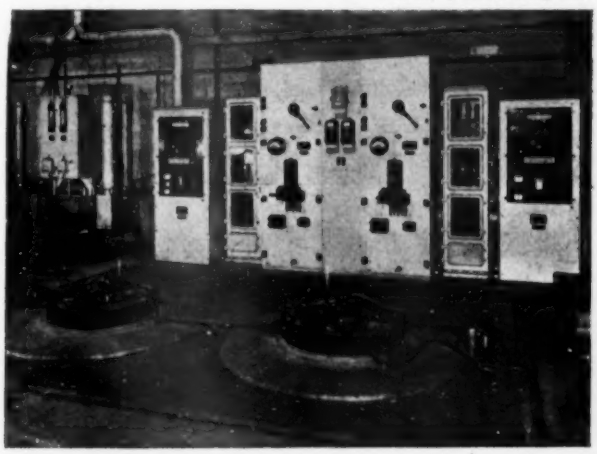


Fig. 11.—A typical heat-treatment furnace control panel controlling a battery of G.E.C. furnaces.

Courtesy of George Kent, Ltd.



A particular development of this equipment is in connection with a recent installation in which two sets of control and recording equipment are used on two 4-zone electrically heated furnaces for normalising large forgings. In this instance, the four zones are each controlled by an individual automatic control pyrometer, whilst the four controllers are operated by one time-cycle or programme regulator. A four-point recording pyrometer is included, which provides a continuous record showing exactly how the required time-temperature cycle has been followed.

Temperature indicating and control instruments covering a number of furnaces are invariably arranged on a panel conveniently located; such a panel is shown in Fig. 11, some of the furnaces which they control are seen in the foreground.

There are a number of manufacturers of reliable instruments of this type, and they are designed for use in heat-treatment shops, the main object being to obtain, as near as possible, the same degree of accuracy possible in the laboratory, but despite their rugged construction reasonable care must be exercised to preserve their accurate functioning and a check should be made at regular intervals as part of the maintenance plan, otherwise a batch of imperfectly heat-treated components may prove more costly.

Personal

Dr. J. S. G. Thomas, formerly senior physicist to the South Metropolitan Gas Co., is now associated with Messrs. Walker, Crossweller and Co., Ltd., of Cheltenham.

Mr. Bernard Thomas, F.Inst.P., F.Inst.F., has been appointed to the Board of The Chillington Tool Co., Ltd., as Technical Director. He will continue as managing director of Midland Heat Treatments, Ltd., of Wolverhampton.

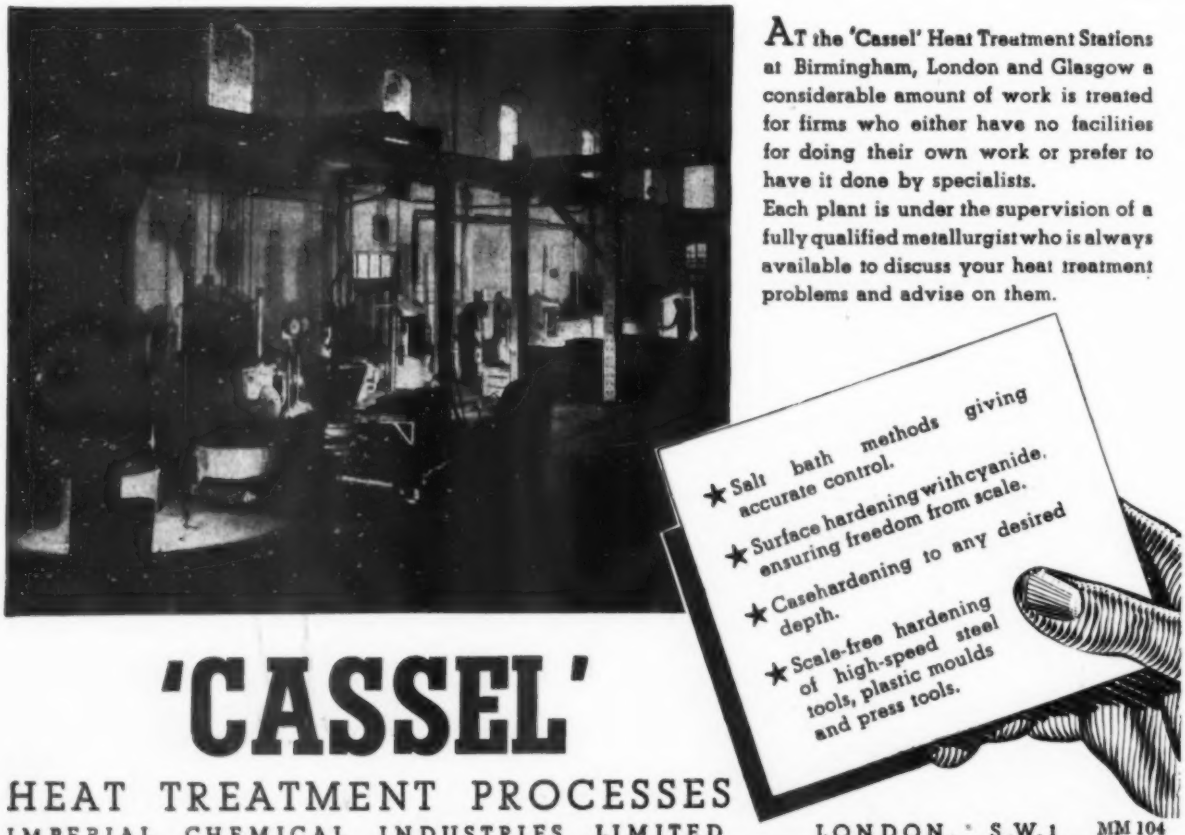
Control of Drop Forgings

In connection with the allocation of drop forgings, which is made by the Materials Committee, now working under the Minister of Production, a scheduling system for drop forgings made on hammers of 20 cwt. and over has for some time been operated by the Departments in conjunction with their contractors, drop forgers, and the Drop Forging Sub-Control. The system has been successful and as from July 1, 1942, will be applied to drop forgings made on *all* sizes of hammers, on upset forging machines, and forging presses. (Forgings made on special shell-forging plant, standard pipe flanges, and tube forgings are excluded).

Under the system, contractors, having contacted their forgers, must submit to the Government Department from which their contracts have been issued or which is responsible for their operations, schedules of their drop-forging requirements for at least three months ahead. The Government Department concerned then checks the schedules and certifies them as covering legitimate requirements. Two copies of the schedules are sent to the forger, one of which he retains and the other of which he sends to the Drop Forging Sub-Control, stating his ability or otherwise to meet the requirements. If the forger is unable to meet the demands made on him, the Drop Forging Sub-Control arranges the necessary capacity elsewhere.

After July 1, 1942, forgers may not produce any drop forgings unless they are covered by authorised schedules. Schedules must be submitted to Departments by the 15th of each month. Schedules for the three months beginning July 1 must be submitted by June 15. Standard Scheduling Forms can be obtained by contractors from the appropriate Government Department.

In any case of doubt, inquiries should be made to the Drop Forging Sub-Control, 263/265, Hagley Road, Edgbaston, Birmingham, 16. (Telephone, Edgbaston 3661.)


AT the 'Cassel' Heat Treatment Stations at Birmingham, London and Glasgow a considerable amount of work is treated for firms who either have no facilities for doing their own work or prefer to have it done by specialists.
Each plant is under the supervision of a fully qualified metallurgist who is always available to discuss your heat treatment problems and advise on them.
★ Salt bath methods giving accurate control.
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★ Casehardening to any desired depth.
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The Grain-size of Rolled Aluminium

The grain size of aluminium sheet and strip of ordinary commercial purity has been studied in considerable detail, special attention being paid to the effects of hot rolling, cold rolling, annealing conditions, and metal purity. The report dealing with this investigation is very extensive, providing a very valuable contribution to this subject, and in this article the main results are summarised.

THE results of a detailed study of the grain-size of aluminium sheet and strip of commercial purity, in which particular attention was paid to the effects of hot rolling, cold rolling, annealing conditions and metal purity, are reported by H. W. L. Phillips.* The initial work of this investigation was the correlation of grain-size and deformation, and the effect of varying the rate, temperature, and time of annealing. The work included a determination of the critical lower limit of strain below which grain growth does not occur on annealing.

As the work proceeded, it became possible to specify the conditions which would be likely to cause excessive grain size in aluminium sheet on annealing, and to formulate some general rules for producing a reasonably fine grain. The application of these rules was not as satisfactory as had been hoped, and as the production of consistently fine-grained metal became increasingly important, a detailed study was made of the effect of what may be termed process variables, such as casting, hot rolling, and cold-rolling conditions. From time to time anomalous results were still obtained, and it was felt that little headway would be made until the question of metal purity had been systematically investigated. The constitution of the aluminium-iron-silicon system was studied† in the hope of obtaining some information on the nature of the phases present in aluminium of commercial purity and on the constitutional effect of working and annealing; and more directly, grain-size measurements were made on a series of samples of different purity rolled and annealed under similar conditions. An increase in the iron content generally tended to make the grain finer, and an increase in the silicon content tended to make them more irregular in size. The scatter, however, was considerable; in spite of very close control of the conditions of fabrication, metal rolled from duplicate blocks in the same mills and to the same thickness frequently differed widely in grain size. It was also noted that samples taken at thick gauges gave, on annealing, sometimes coarser and sometimes finer grains than others taken from the same sheet or strip at thinner gauges. Many attempts were made to find the cause of these anomalies, and the present report embraces the main features of a comprehensive study of the grain size of rolled aluminium. The paper is divided into eight sections and deals with methods of measuring grain-size; preliminary correlation of grain-size with deformation imposed prior to annealing; the effect of annealing conditions; the least amount of strain necessary to cause grain growth; deliberate strain and temperature gradients; the effect of process variables; the correlation of grain-size with purity; and the cause of grain-size irregularity.

Methods of Measuring Grain Size

The mean grain-size was obtained by counting the grains on polished and etched micro-sections, and throughout the paper the grain-size is expressed as the number of grains per square millimetre of etched surface. The author recognises that the figure is a conventional one. Annealed metal consists of irregularly shaped grains of varying size, which are cut in a haphazard manner by the plane of polishing. The area of the grain section as seen under the microscope depends on the size and shape of the grain and on the distance of the plane of polishing from the diametral section, and thus bears an intermediate relationship to the true size of the grain. For routine use, an accurate knowledge of the average size of the grains is not necessary; comparative figures are all that are needed, and by retaining one standard method throughout, it has been possible to collect data covering process changes over a period of years. The method used to determine the grain size, both parallel to and at right-angles to the rolled surface, is described.

Preliminary Correlation of Grain Size with Deformation Improved Prior to Annealing

Four series of experiments were made to obtain some preliminary information about the relationship between cold-work and grain-size. In each series a rolling block of standard dimensions was hot-rolled to a thickness of about 0·25 in., and set aside to cool. It was then cold-rolled, either in the sheet or strip mills, and portions were set aside at intervals throughout the process, samples were taken for micro-examination, and the grain-size was determined. In this way a curve was obtained, showing the relationship between the grain-size and the deformation imposed on the metal during cold-rolling. The portions of annealed sheet or strip were then cold-rolled to a constant finishing thickness and annealed again. In this way a second series of samples was obtained, differing in the amount of cold-rolling they had received between the intermediate and final annealing operations. The anneals were carried out at a temperature of 450° C., the metal being retained in the muffle for 2½ hours. The particulars of the metal used are given in the accompanying table, and the grain-size figures for each series are plotted in Figs. 1 and 2.

Series.	Finishing Thickness, In.	Method of Processing.	Analysis.		
			Iron, %.	Silicon, %.	Aluminium, by Difference
I	0·036	30 in. wide sheet*	0·47	0·24	99·29
II	0·064	16 in. wide strip*	0·56	0·48	98·96
III	0·040	16 in. wide strip	0·43	0·30	99·27
IV	0·028	30 in. wide sheet	0·45	0·48	99·07

* The production of strip differs from that of sheet in two important respects: (1) The pinches in strip rolling are usually heavier than in sheet rolling. (2) In strip rolling, the metal is subjected to tension set up by the coiling mechanism.

In Fig. 1 the grain-size of the singly annealed samples has been plotted against the thickness and not against the percentage of deformation, since the latter is only approximately known. During the later stages of the hot-rolling process, recrystallisation does not keep pace with deformation, with the result that the metal is cold rolled to a slight but indefinite extent. In Fig. 2 the grain-size of the samples intermediately and finally annealed has been plotted against the percentage deformation imposed between the two anneals. The results confirm the findings of previous workers, that the grains are finer the greater the deformation, but it is clear that deformation is not the sole factor governing the grain size.

The Effect of Annealing Conditions

A few experiments sufficed to confirm the deductions of other workers that a slow rate of heating to the annealing temperature of 450° C. tended to produce large grains. Holding at the annealing temperature resulted in some

* H. W. L. Phillips. *Jour. Inst. Metals*, 1942, **68**, 47.
† A. G. C. Gwyer and H. W. L. Phillips. *Jour. Inst. Metals*, 1927, **38**, 29.

additional grain growth of the rapidly heated specimen; this grain growth, however, did not eliminate the difference between rapidly and slowly cooled specimens under the conditions of the experiment. In other experiments the difference in the grain size of rapidly and slowly heated specimens was much less, and it is possible that such differences may become masked by grain growth at the higher temperatures.

Cold-rolled sheet specimens annealed for various periods of time at 350°, 450° and 550° C., respectively, were found to have attained a constant grain-size after about 3 hours at 350° and 450° C., while in specimens annealed at 550° C.

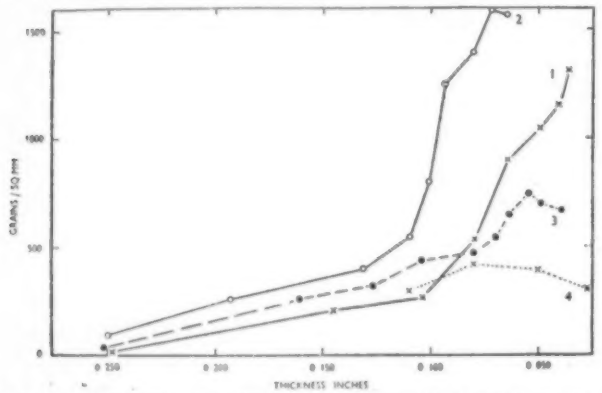

Fig. 1.—Grain size of aluminium sheet and strip cold-rolled to various thicknesses and annealed.

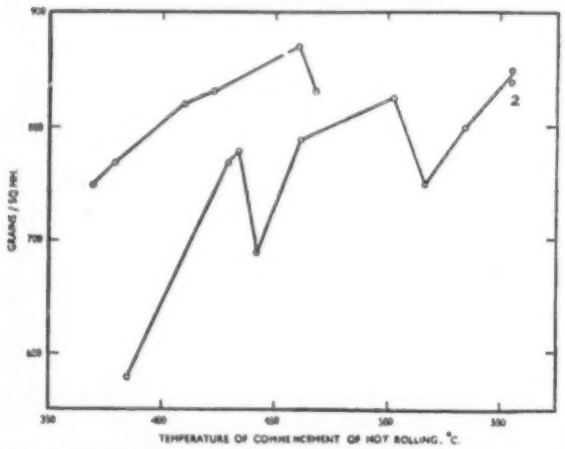

Fig. 3.—Effect of hot-rolling temperature. Metal strip rolled to 0.036 in. without intermediate annealing.

grain growth was still found to be proceeding slowly after 4 hours. With other samples, differing in finishing thickness and purity, annealing at 450° C. did not give consistent results, some samples attaining a constant grain-size, while in the case of others the initial period of comparatively rapid grain growth was followed by slow grain growth, equilibrium not being reached within the 10 hours for which the experiment was continued. In annealing metal of medium temper which had been produced by cold-rolling with an intermediate anneal, the large grains formed in lightly worked metal (18 and 29% reduction), exhibited no grain growth (at 450° C.), very little growth occurring in samples reduced 37%. With heavier reductions and finer grains, growth became increasingly pronounced.

In experiments on the medium temper metal in which annealing was carried out at different temperatures, grain growth after recrystallisation was masked by the effect of the rate of heating through the recrystallisation range; the grain-size in lightly worked samples annealed at 600° C., being finer than at the lower temperatures. In the more heavily worked samples, annealing at 450° C. gave finer grains than did annealing at 350° C., suggesting that here also the effect of rate of heating predominated. In samples annealed at 600° C. grain growth had apparently occurred, and had more than counterbalanced the effect of rate of heating.

The conclusions were not confirmed in a repeat experiment, in which metal of four different purities were used. In this experiment, instead of finish rolling at a constant gauge, the initial gauge was fixed (0·048 in.) and the metal was strip-rolled to various thicknesses to give reductions of 14, 26, 50 and 75%. In every case the metal annealed at 600° C. possessed the coarsest grains, and in almost every case that annealed at 450° C. had the finest.

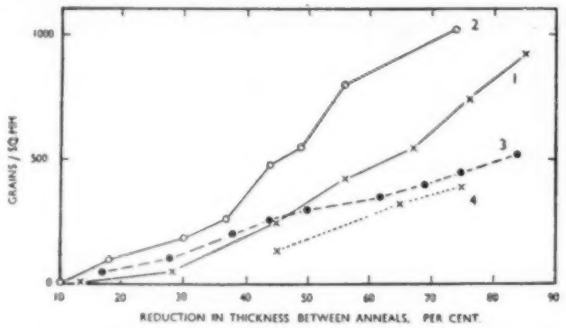

Fig. 2.—Grain size of aluminium sheet and strip intermediately annealed at various thicknesses, rolled to a constant finishing thickness and re-annealed.

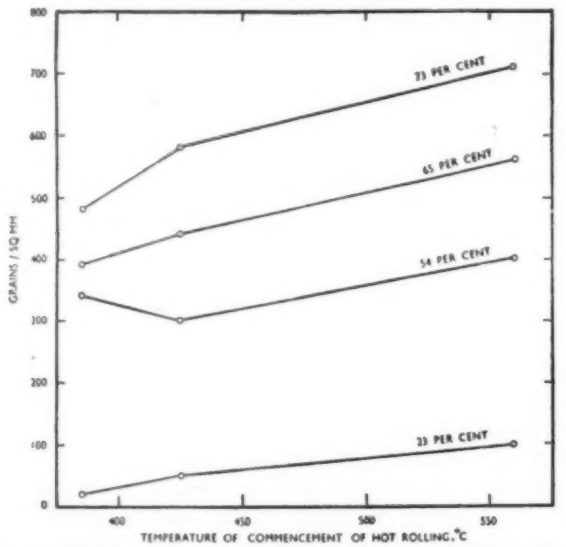

Fig. 4.—Effect of hot-rolling temperature. Metal intermediately annealed at 0.104 in. thickness, cold rolled to various thicknesses and re-annealed.

The Least Amount of Strain to Cover Grain Growth

At the outset of this research, investigation of the recrystallisation of lightly worked aluminium was urgently needed, owing to the prevalence of exaggerated grain growth in spinnings and pressings. Where the forming operations were severe, it was often the custom to give one or two anneals during the process, in order to obtain a little extra ductility. If the metal was critically fully annealed, the first operations during forming produced a strain gradient in the articles of such a character that a band of large crystals was produced on reannealing, either at the junction of base and sides, or at a little distance up the sides, rendering the metal useless for further spinning or pressing. It was therefore thought advisable to study the relationship between the critical lower limit of strain at which the largest grains were formed on annealing and the annealing temperature; and also to determine whether lightly worked

metal would be softened by annealing at a temperature below that at which recrystallisation occurred.

Several series of experiments were made on tensile test-pieces prepared from aluminium sheets and strips of different purities, and the tensile machine was used to apply the desired strain. The test-pieces were strained from zero to 25% and then annealed for 2½ hours at 350°, 400°, 450° and 600° C., and roughly polished and etched. The results obtained show that the critical lower limit of strain increases rapidly as the annealing temperature is reduced, and also that the lighter the deformation, the higher is the temperature required for recrystallisation. A large measure of mechanical softening could be achieved without recrystallisation occurring. Where the critical lower limit has been exceeded, and recrystallisation has occurred, the grains are in all cases smaller the higher the annealing temperature.

Deliberate Strain and Temperature Gradients

It has long been known that very large crystals may be formed in metal which has been subjected to a strain gradient. Thus, if a fully annealed test-piece is stressed to fracture and reannealed, the largest grains of all form in the shoulders. Results of investigations suggest that growth stops at a certain definite limit of stress, and to find whether the limit is the same on the strain gradient as in uniformly strained material. Test-pieces cut from the same sheet were stretched by various amounts and their hardness was determined. They were then annealed for 2½ hours at 450° C., when it was found that the largest crystals formed in the test-pieces having a hardness of 7–7½ on the scleroscope scale, and that softer metal did not recrystallise. It is shown that the outer edge of the large crystals is roughly coincident with the 7¼ scleroscope hardness line, and it is inferred that the large crystals would have formed their present position in any case, and that the existence of the strain gradient did not modify their growth. The same was found to be the case as regards the effects of a temperature gradient on work-hardened samples.

The Effect of Process Variables

The investigation of the effect of process variables included a study of the effect of casting conditions, hot-rolling conditions, and cold-rolling conditions. For studying casting conditions, standard rolling blocks were cast, the pouring temperature of the metal ranging from 680° to 800° C., and that of the moulds from 25° to 330° C., both factors being varied at random through the experiment. Difference in casting conditions, however, did not cause any significant difference in the final grain-size.

The main effect of hot-rolling conditions was manifested in a tendency of the grains to become finer as the temperature, at which hot-rolling was commenced, increased. Four series of experiments were made in which the temperature of commencing hot rolling was intentionally varied. In the first two series, metal of two different purity ranges was used, and the hot-rolling temperatures were varied within the range 370°–550° C. Apart from this, the rolling treatments or the two series were identical. The blocks were hot rolled to a thickness of 0·41 in., allowed to cool, and then cold rolled in the strip mill to a finishing thickness of 0·036 in. Duplicate samples from each strip were simultaneously annealed for 2½ hours at 440°–460° C. In the third series, blocks of the same purity were hot rolled to a thickness of 0·104 in. and were then annealed. Samples from each annealed blank were rolled in the strip mills to various thicknesses, and were finally annealed in one batch for 2½ hours at 450° C. In the fourth series, duplicate blocks covering a wide range of purities were hot rolled to a thickness of 0·40 in., one of each pair being rolled at a temperature in the range 500°–530° C. and the other at 380°–390° C. After cooling, each blank was sheared into two parts, one being cold rolled in the sheet mills, using light reductions, and the other in the strip mills, using heavy reductions. The finishing thickness for both sheet and strip was 0·049 in. Samples were annealed simultaneously for 2½ hours at 450° C. Particulars of the metal and treatment are summarised in the accompanying table.

Series.	Range of Composition.		Intermediate Annealing Thickness, In.	Finishing Thickness, In.	Reduction in Thickness between the two Anneals, %.
	Silicon, %.	Iron, %.			
1	0·21–0·26	0·52–0·55	Nil	0·036 strip	Nil
2	0·19–0·23	0·28–0·37	Nil	0·036 strip	Nil
3	0·25	0·49–0·51	0·104	0·080 strip 0·048 0·036 0·028	23 54 65 73
4	0·21–0·73	0·20–0·78	Nil	0·049 sheet and strip.	Nil

The mean grain-size figures for series 1 and 2 have been plotted, and are reproduced in Fig. 3. It will be noted that in both cases there is a tendency for the grains to become finer as the temperature of commencing hot rolling increases. From a theoretical point of view, the results of the experiment are extremely interesting, since the general relationship between grain-size and hot-rolling temperature is the converse to that which had been expected.

The main grain size for series 3 have been plotted, and is reproduced in Fig. 4. Again, in almost every case, a higher hot-rolling temperature is associated with finer grain. From the practical point of view, these figures are of interest as showing the difficulty of standardising a safe intermediate annealing point. In series 4 only two hot-rolling temperatures are employed, and it was thought better to plot the grain-size figures for the various treatments against the iron content. This has been done in Fig. 5.

It will be seen that in every case the metal hot rolled at the higher temperature is the finer grained, though in certain instances, with low percentages of iron, the differences are small and might disappear or be reversed in a repeat experiment. The result of these four experiments may be summed up by saying that while it cannot be stated with certainty that a high hot-rolling temperature will result in fine grains, there is, nevertheless, a strong probability of its doing so.

Cold-rolled material reduced without intermediate annealing to the same final thickness was found after annealing to possess a different grain-size, depending on whether it had been rolled as sheet or strip, the strip-rolled metal being the finer grained. Further experiments did not always confirm these results, sheet-rolled specimens frequently having a finer grain than strip. Again, there was a certain tendency for the grains to be finer as the iron content increased, while differences in grain-size between sheet and strip tended to decrease in samples of low iron content.

Samples rolled down, both as sheet and strip, to different finishing thicknesses, gave number of grains/mm.^{2} final thickness curves, most of which had a maximum corresponding with a thickness of specimen of 0·05 in. to 0·08 in. The consequent difficulty of producing thin metal in a finely grained condition may be overcome by subjecting the metal to an intermediate anneal. No maxima in the number of grains/mm.^{2} curves of metal so treated have hitherto been observed. The intermediate anneal should be sufficiently removed from the finishing thickness. If the reduction of the intermediately annealed metal is carried sufficiently far, a maximum in the number of grains/mm.^{2} curve may be encountered, but in any case the metal will have a finer final grain-size than metal cold rolled without an intermediate anneal.

Results obtained with metal on which heavy reductions were imposed in cold rolling are also reported. Very fine grains were obtained, even in relatively thin metal, and maxima occurred in the curves for metal annealed before the intensive reductions were imposed, but not in those for initially hard metal.

The Correlation of Grain Size with Purity

In an attempt to correlate grain-size with purity the constitution of commercial aluminium—the aluminium corner of the aluminium-silicon-iron system—is considered. Equilibrium is not reached during solidification under conditions encountered in practice, and the number of phases present in the cast metal is in excess of that which theory would require. In addition to aluminium, free silicon, and the binary compound $FeAl_3$, two ternary phases occur, α (Fe-Si) and β (Fe-Si), α (Fe-Si) is found to persist at room temperatures, due to lack of equilibrium. With prolonged annealing it is completely converted to the β body, leaving the latter the only stable ternary phase over a wide range of compositions in the aluminium corner. $FeAl_3$ and α(Fe-Si), persisting to the cold-rolling stage, tend to remain in comparatively large fragments, whereas the β body, which is brittle and crumbles readily, tends to become distributed throughout the metal in a fine state of sub-division. It would, therefore, be expected that maximum conversion of $FeAl_3$ and α to β would give the greatest number of particles acting as obstructions to grain growth, and hence tend to give the finest-grained product. This is a possible explanation of the beneficial effect of a high hot-rolling temperature which has been referred to above.

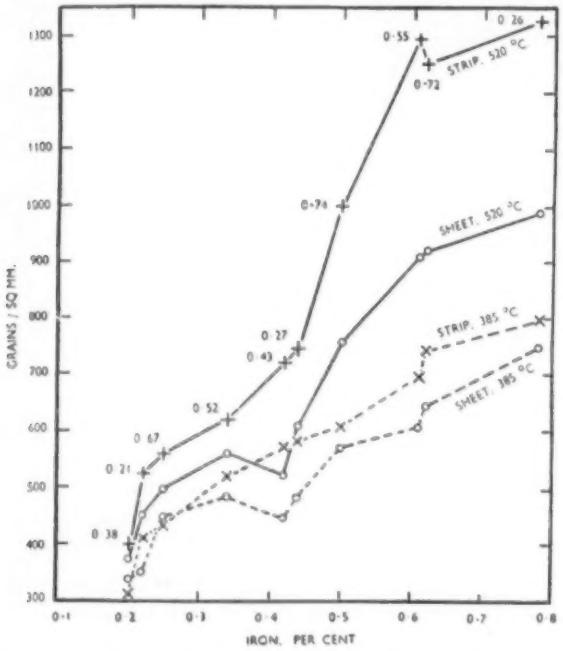

Fig. 5.—Effect of iron content, hot-rolling temperature, and type of cold rolling on the grain size.

A mean curve drawn through a scatter diagram (Fig. 6) in which number of grains/mm.^{2} is plotted against the iron content, shows that the grain decreases with the iron content over the range of 0·1 to 0·6% iron, the slope of the curve increasing with the iron content. Although iron acts as an obstruction to grain growth in aluminium, it does not seem to affect the recrystallisation temperature; this may, perhaps, explain why increasing the iron content does not appear to lead eventually to grain coarsening.

Under the conditions of annealing employed, silicon did not appear to have a pronounced effect on the grain-size. High silicon contents tended to favour irregularity of grain-size. While an increase in the silicon content should, theoretically, increase the amount of β (Fe-Si) relative to $FeAl_3$ and α (Fe-Si) and thereby favour the development of a fine grain, the effect, if it exists, seems in many cases to be masked by the operation of other factors. The same applies to the effect of intermediate anneals which, too, should favour the formation of β (Fe-Si) and thereby of fine grains.

In considering the effect of minor metallic impurities, it has been found that copper up to 0·1% had no effect on the grain-size of aluminium strip. Manganese present in amounts less than about 0·25% has little or no effect on the grain-size of rolled aluminium, but at that figure irregularity of grain-size becomes apparent, leading, at still higher percentages, to marked general coarsening of the structure. Titanium with its well-known grain-refining effect on the structure of cast aluminium has a less pronounced effect on the grain-size of wrought alloys, being very similar in this respect to iron. Zinc added in amounts up to 1% was found to have no effect on the recrystallisation temperature and grain size. Sodium was found to have no effect on grain size.

The effect of minor non-metallic impurities (alumina, aluminium nitride, carbon, aluminium carbide, phosphorus, sulphur and dissolved gases) was not studied, but from the small amounts present it is considered unlikely that they can affect the grain-size materially.

The Cause of Grain Size Irregularity

The early stages of the recrystallisation process have been considered in connection with grain-size irregularity. It is mentioned that mean figures for duplicate blocks were often discordant, varying in one example between limits of 280–460 grains/mm.^{2} There were also variations in grain size across the width of a sheet or strip. Samples taken from near the edges were generally, though not always, finer than those from the centre line, and in some cases the differences amounted to 300–400 grains/mm.^{2}

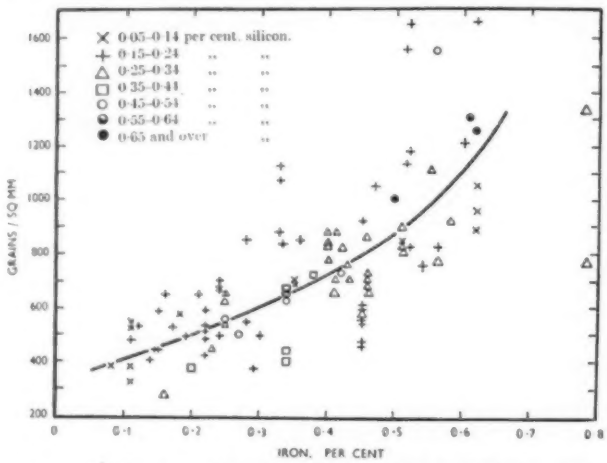

Fig. 6.—Grain size data for all samples of 0.049 in. and 0.036 in. strip. Finally annealed only.

Experiments in connection with the existence of the maxima on the number of grains/mm.^{2}/cold-work curves showed that grain growth after recrystallisation occurred to about the same extent in the thinner and thicker samples derived from one and the same block. Recrystallisation, however, commenced first and was completed first, in the thinner material. The resistance to absorption is thus reduced, as would be expected, by the further cold-work imposed on the thinner material. It follows that the coarser grain frequently found in the thin sheet or strip must be due to the greater activity of the growing crystals. The maximum in the curves can, therefore, be explained as being the result of two opposing factors: the number of nuclei at recrystallisation, and the activity of the growing crystals. With relatively light degrees of deformation, the former predominates and the metal becomes increasingly fine-grained; whereas with relatively heavy degrees of deformation the activity factor seems to predominate and the metal tends to become increasingly coarse-grained.

Microscopic examination of the boundaries between the

crystallites oriented to a certain extent by cold-rolling, showed that some of these boundaries were more prolific as a source of new crystals than others, and that some of the original crystals were more resistant to absorption than others. Laue photographs showed that lattice distortion and fragmentation occurred to a greater extent at the boundary than at the centre of the crystal. The deformation at the boundaries is largely determined by environment, and it is not surprising that no two behave alike during recrystallisation. It has also been pointed out that diffusion of soluble impurities to the crystal boundaries frequently precedes recrystallisation, and this may be another factor contributing to the difference in behaviour between the various boundaries.

The number of new crystals appearing during the initial stages of recrystallisation thus depends on many factors, the most important of which seem to be the number of particles of impurity, the number of the more prolific crystal boundaries, and the degree of work-hardening.

In the earliest stages of recrystallisation in metal rolled without intermediate annealing, new crystals appeared in the surface layers at lower temperatures than in the central portion, the difference being of the order of 10°–20° C. This behaviour could not be explained by differences in purity caused by normal or inverse segregation in the cast block, as these differences in the rolled material were shown to be insignificant. No correlation could be observed between the fibre structure and the recrystallisation.

The cause was traced to lack of uniformity of the structure of the hot-rolled metal. The surface was found to consist of recrystallised material, whereas the centre possessed a markedly cold-worked structure and was appreciably harder. X-ray examination of samples taken at intervals during cold-working showed that the surface layers remained different from the interior, even at thin gauges, the orientation of the crystallites being less preferred. Annealing experiments confirmed that the difference between surface and interior persisted to thin gauges; on recrystallisation the new crystals invariably appeared at a lower temperature in the surface layers. Intermediate annealing of the cold-rolled metal eliminated all differences between the surface layers and the interior and a uniform grain size was subsequently obtained throughout the thickness.

Apart from variations due to chance, five possibilities are considered; the differences in question may be due to differences in purity, casting conditions, hot-rolling conditions, cold-rolling conditions, and annealing conditions.

Heat-Treatment of Alloy Cast Irons*

TO harden cast iron by heat-treatment, it must be heated above the critical range and quenched in oil, water or air from above that range. As in the case of steel, the initial stage of the critical range will depend upon the combined carbon present. However, this also is affected by other elements occurring in cast iron, such as silicon, manganese and other alloying elements.

It has been established that the critical cooling rate for maximum hardness of plain 0·80% carbon steel is approximately 300° F. per sec. The rate for a 3% nickel steel, practically free from silicon, is approximately 30° F. per sec., and if other alloys, such as molybdenum and chromium, are included, this rate may be reduced to as low as 6°–10° F. per sec. There is no similar data for nickel cast iron, but it has been shown by many investigators that the trend is comparable to that of nickel steel.

The core of a plain iron heavy casting does not give up its heat fast enough to obtain maximum hardness when quenched in oil. Since the critical cooling rate of iron for maximum hardness decreases with increasing alloy additions, it can be expected, therefore, that with increasing alloy additions, the core hardness of a heavy alloy iron casting, when quenched above the critical range, will approach the surface hardness of the casting.

Annealing consists in heating an iron casting to a relatively high temperature for a definite period of time and permitting it to cool slowly. Its usual purpose is to reduce hardness in order to facilitate machining, in other cases, however, it may be adopted to relieve castings of stresses. In low alloy irons, annealing is accomplished by heating the casting to some temperature above 540° C. and under 900° C. Care must be taken to control the anneal, so that graphitisation does not become too extensive and the strength become excessively reduced. Alloy grey irons are less susceptible to damage during annealing, because elements such as nickel, molybdenum, chromium, vanadium, etc., retard the rate of carbon migration and pearlitic carbide decomposition, preventing loss of dissolved carbon either by oxidation or graphitisation.

Ageing or stress relief annealing of alloyed castings, without materially affecting physical properties, is usually carried out in the temperature range of 450°–600° C.; the usual rule of heating 1 hour per inch of section being applicable. Slow cooling, or at least cooling in still air from the annealing temperature, is generally practised to avoid setting up new stresses in the castings.

When heated above the critical range and cooled at an accelerated rate, cast iron follows the same characteristic reactions that steel does if treated in the same manner. Quenching of cast iron is usually resorted to in order to obtain maximum hardening, except in the case of high alloy, partially austenitic castings which may be quenched for obtaining softness. In some instances, castings are used in the quenched condition, but usually they are tempered between 100° and 320° C. to relieve quenching stresses, without material reduction in hardness, where wear resistance and not material strength is most important.

An iron most suitable for heat-treatment should have a finely distributed graphite flake structure, a matrix free from carbides, and a full pearlitic or sorbitic structure containing 0·60 to 0·80% combined carbon throughout the section.

Nickel Cast Iron News, vol. 13, No. 1.

Classification of Copper and Copper Alloys

THE enormous range and variety of the copper and copper-base alloys which are in commercial use has in the past always presented a problem to engineers and designers faced with the task of specifying materials, and, at the present time, when many firms are engaged in the fabrication of products and materials with which they are not fully familiar, the difficulties of the situation are more widely experienced. Tabulated data concerning the more important copper-base alloys, with a citation of appropriate British specifications, such as are presented in a booklet, recently issued by the Copper Development Association, will therefore be helpful at the present time.

The 17 tables given in this booklet cover the main types of copper and copper-base alloys now in use, they were first published, in a slightly modified form, in October, November and December, 1941, issues of this journal, and the demand for copies indicates that this booklet will fill a special need in the present emergency. In this booklet the data are presented in a useful form, and the tables are suitably arranged for convenient reference. Copies may be obtained on application to the Copper Development Association, 9, Bilton Road, Rugby, Warwickshire.

Ilford Kryptoscreen X-Ray Paper

THIS unique product, which marks an entirely new departure in the field of radiography, is the latest of a range of Ilford products especially intended for the X-ray worker. Before describing its special properties and uses, it will be of interest to review briefly the evolution of sensitised materials for radiographic purposes from the time when practical use was first made of X-ray photography.

The first X-ray photographs were made on the standard photographic plates of the time, but soon means were sought for increasing sensitivity to X-rays, which, by reason of its penetrating power, passed through these plates almost entirely unabsorbed and therefore with very little photographic effect. The silver bromide emulsion, when exposed to X-rays within the wave-length range normally employed for radiography, absorbs less than 1% of the incident radiation. The response to X-rays of the earliest plates was increased by coating them very thickly with an emulsion containing an unusually high concentration of silver bromide. This expedient succeeded in reducing the time of exposure, but it created a serious problem in processing; because of the thickness of the gelatine layer, development was usually incomplete and fixation was difficult.

The introduction of thin flexible celluloid film, however, solved this problem, making it possible to achieve the same radiographic effect as had been obtained from the thickly coated glass plates by coating both sides of the film with emulsion layers of normal thickness, thus eliminating the processing difficulties. Double-coated films are to-day the standard medium for all forms of X-ray work.

A further step towards reducing exposure time was obtained by the introduction of intensifying screens. These consist of a cardboard base on which is coated a layer of a salt, such as calcium tungstate, which, when exposed to X-ray, fluoresces more or less brightly—i.e., emits visible radiation, according to the intensity of the rays. Two such screens are employed with double-coated films, one on each side, and they reinforce the action of the X-rays.

For certain purposes it has been found that X-ray paper, which consists essentially of a paper base coated on one side with X-ray emulsion, can be used as a substitute for X-ray film. The results, although inferior in contrast and density to those given by film, are sufficiently good for certain types of work and provide an economical medium; thus, when the radiography of a large number of similar parts is to be undertaken, it has been found by previous tests that paper is capable of revealing in a satisfactory manner the defects for which the parts are being examined. Only one intensifying screen, of course, can be used with paper, and ordinary X-ray is therefore handicapped, in comparison with film, by inferior speed.

This new Kryptoscreen X-ray paper, on the other hand, is a product from which the disadvantages of ordinary X-ray paper are notably absent. Beneath the emulsion coating is a coating of extremely fine-grained fluorescent material, which, without in any way impairing definition, achieves the double purpose of shortening exposures and greatly improving the gradation of radiographs made upon the paper. In other words, this new X-ray paper incorporates its own intensifying screen.

The search for a fluorescent material which neither lowers the sensitivity of photographic emulsions nor impairs definition and which can be produced at a sufficiently low cost to be used in the above manner has been carried on by the Ilford Research Laboratories for many years. The successful attainment of this object has made it possible to offer, in Kryptoscreen paper, a material which will undoubtedly find many valuable applications, particularly in the growing field of industrial radiography and in all cases where the delineation of the finest detail is essential. The definition of radiographs produced on Kryptoscreen is of the highest order; in comparison with the ordinary X-ray paper and calcium tungstate screen combination, it is but little inferior in speed and is markedly superior both in contrast and definition.

As a means of further increasing the effective speed of this X-ray paper, the new fluorescent material has also been employed in the form of a coating on flexible card to produce the Brytex Intensifying Leaf. When Kryptoscreen paper is exposed with its sensitive surface in contact with a Brytex Leaf, the emulsion is in effect sandwiched between two fluorescent layers, so that the paper is being used in the same way as double-coated film exposed between a pair of intensifying screens. Because of its exceedingly fine grain, the Brytex Leaf permits a reduction in exposure to one-third of that required by Kryptoscreen paper alone while preserving to the greatest possible extent its perfect definition. The standard of definition attainable by the combination is superior to the best results obtainable with high-definition screens either on film or paper.

Handling, Storing and Transporting Wrought Aluminium Alloys

IT is true to say that real conservation of metals can be achieved by the constant use and re-use of that part of production which is not destroyed in service, the prudent use of natural resources, and the efficient use of combinations of metals in the form of alloys. There is, however, another aspect of this subject of conservation of metals that is frequently overlooked and which is responsible for considerable waste; we refer to the handling, storing and transporting of finished and semi-finished materials.

It is extremely important at present, when every effort must be made to utilise all our resources, that waste should be reduced to a minimum, yet a considerable quantity of valuable metal is scrapped, due to careless handling in workshops, during packing and in transit, while faulty storage conditions frequently cause serious conditions. Although figures for such wastage cannot be given, for obvious reasons, they are too high, and the Wrought Light Alloys Development Association, by describing elementary precautions to avoid waste of this character, as far as it concerns wrought aluminium alloys, is doing a very useful service.

The subject is discussed in the Association's first bulletin. The object of this booklet is to explain the necessity for care in handling and subsequent storing of wrought light alloys, and to describe the measures which should be taken in the works to avoid damage. The information given is both explicit and timely. It should be noted that, by comparison with other metals, the risk of damage to aluminium alloys by corrosion is small, but trouble is sometimes experienced when they are stored for long periods in unsuitable conditions.

The basic factors of the subject are discussed, storage conditions, precautions during storage, handling, and transport, are also admirably considered, and the booklet concludes with an appendix giving the identification colouring for aluminium and aluminium alloys standardised by the A.I.D., which should be especially useful to all personnel responsible for the storing and transport of these alloys. Requests for copies of this booklet, and for posters, which are also available, should be addressed to the Manager of the Association, 34, New Street, West Bromwich.

The *Nickel Bulletin*, volume 15, No. 3, includes a description of a new American immersion type tungsten-graphite thermocouple for the rapid measurement of molten iron and steel. Other work of interest deals with bright plating, wetting agents in electro-deposition, the electrical resistance of high manganese-nickel-copper alloys, weldability tests for steels and the " Shotweld " process of welding stainless steel. Copies may be obtained free of charge from the Mond Nickel Co., Ltd., Grosvenor House, Park Lane, W. 1.

Hardenability of Steel

Although hardenability of steel can usually be evaluated on the basis of composition, grain size, hardening temperature, quenching rate, etc., there is occasionally a steel of anomalous behaviour. In this summary an investigation on the possible relation of dendritic segregation in the ingot to such behaviour is discussed and a test for segregation given.

IN appraising and selecting steels for engineering and machinery purposes, the property of hardenability is one of the most important to be considered, and can usually be evaluated on the basis of composition and grain size specifications. There is, however, an occasional steel of anomalous behaviour, the hardenability of which cannot be predicted on the basis of composition, grain size, hardening temperature, quenching practice, and surface condition, and with the controlled technique of hardening this anomalous behaviour of certain steels can be ascribed to characteristics of the steel rather than to conditions imposed in the hardening operation.

During recent years considerable attention has been given to the detection and estimation of elements in steel other than those included in normal steel specifications, and there is reason to believe that as a result of such investigations part, if not all, of the explanation of discrepancies in hardenability may be found. There is also reason to believe that the common description of the physical state of steel is inadequate, and that in addition to grain size, which now constitutes the principal relationship between the physical state and the hardenability, the degree of heterogeneity, which arises from dendritic segregation in the ingot ought to be considered in describing the physical state of steel. The recent description of a test developed by Parke and Herzig[1] for such segregation is therefore of interest.

Several investigators have indicated that there is some relation between segregation and hardenability, and the general opinion is that better hardenability is associated with better homogeneity, although there are certain exceptions to be noted. In carbon steels, non-metallic inclusions generally initiate the transformation of austenite to pearlite, but in alloy steels transformation is observed to be initiated more often than not in areas quite free from non-metallic inclusions, and when it is remembered that regions high in inclusions will also be high in alloying elements, it is obvious that the nucleating effect of inclusions may be offset by the greater amount of alloy in these areas. In such cases, segregation may enhance rather than detract from hardenability.

To understand the relationship between segregation and hardenability, an exact method of measuring the extent of heterogeneity is necessary. The distance between the centres of a high-alloy region and the adjoining low-alloy region in a segregated steel is a matter of a few thousands of an inch. Chemical analytical methods are not directly applicable, and while spectro-chemical methods have shown promise, they have yet to be developed to a point where such small samples can be analysed with confidence, although work[2] along such lines has been carried out. In a microscopic test, any direct relationship between microscopic segregation and hardenability must be based primarily on the occurrence within the steel, through segregation, of portions having critical cooling rates greater and less than the critical cooling rate of the average composition. A test for segregation must therefore be based on the direct determination of the time required for 50% of the austenite to transform in each of these two portions of the steel, when transformation takes place at temperatures in the regions of the nose of their S-curves, and a relationship between these times selected which will measure the degree of segregation as far as its effects on hardenability are concerned.

In carrying out such a test, the temperature at which transformation of the areas or bands is to be determined has to be selected with care. In steels of low hardenability it is rather difficult to follow the progress of transformation at the nose of the S-curve, therefore it is generally advisable to select a temperature above or below such a point. A temperature of 595° C. is best suited for steels which transform largely to lamellar products on cooling through the zone of fast reaction rate, while for steels transforming largely to acicular products, when cooled at less than the critical cooling rate, a temperature of 455° C. is more suitable.

If samples of a segregated steel are isothermally treated at either of these temperatures for various lengths of time and the resultant structures examined, some areas or bands are found to begin to transform before others. The percentage of austenite transformed in a given time in each band may then be determined by imposing a grid on the photograph of the structure and estimating the percentage of austenite in each square. If the transformation of austenite is in a temperature region where the reaction is initiated at grain boundaries, then the length of the rows of the grid must be several times the average grain diameter, so that the different rates of transformation within a grain may not confuse the determination of the rates in different bands.

By plotting the percentage of austenite transformed in each vertical row against distance at right angles to the bands, a wave-like curve is obtained. Each peak of this curve gives the percentage of transformed austenite in a low alloy region, while each valley gives the percentage of transformation in a high alloy region. The average of the peaks may be taken as the percentage of transformed austenite in the low alloy regions, and the average of the valleys the percentage transformed in the high alloy regions. When the percentage transformed in each of the two extreme regions is plotted against time at constant temperature a curve may be drawn which permits estimation of the times for 50% transformation in both the high and low alloy regions, and the difference in these times divided by the average time is arbitrarily taken as the segregation factor. By such a method a perfectly homogeneous steel has a segregation factor of zero, while the factor for the extreme case of segregation approaches 2 as a limiting value.

In the process of hot-working an ingot into a bar, the dendrites are stretched out into thin rods of polygonal cross-section, and in examining the banded structure metallographically on a plane parallel to the axis of these rods, it is found that such a plane selected at random will frequently fail to pass through the centre, or lowest alloy region, of some of the intersected rods, but will always pass through the high-alloy region of each rod intersected. The grid, therefore, should traverse as many bands as possible to ensure that each representative structure has been examined, and even so, the time for 50% transformation of the low alloy regions will generally be determined as too long, but this error may be reduced by selecting only the taller peaks.

This test for segregation has been applied to several samples of steel. A steel containing 0·39% carbon,

1 *Metals and Alloys*. 1942, vol. 15, No. 2, pp. 211–244.
2 F. G. Barker. *J. Iron Steel Inst.* 1939, vol. 139, pp. 211–255P.

1·87% manganese, 0·18% silicon, 0·018% sulphur, 0·023% phosphorus, 0·013% molybdenum, 0·11% nickel, and 0·06% chromium, as rolled, was found by the method described to have a segregation factor of 0·70, and after heating for 80 hours in vacuum at 1,265° C. the segregation factor was reduced to 0·26. The hardenability of this steel before and after the homogenising treatment was most marked. Another steel containing 0·45% carbon, 0·78% manganese, 0·24% silicon, 0·22% molybdenum, 1·11% chromium, 0·087% nickel, having a McQuaid Ehn grain size of 7·8, had segregation factors of 0·645 and 0·39 before and after homogenising, and a marked increase in hardenability at depths over $\frac{3}{4}$ in. in the segregated condition.

Low-Grade Ores for America's War Production Programme

NOTHING is being left to chance in the preparations made by the United States to bring their vast resources into action in this present struggle. The huge war production schedule presented by the President has necessitated a complete study of the problems arising from it, and although much has already been done and much development work accomplished, a long view is taken of the whole situation. Among the many problems to receive special consideration in this production drive is the question of minerals and details of a programme to use low-grade domestic ores to make the United States more independent of foreign minerals, during the present emergency, have been submitted by Mr. Harold L. Ickes. It has been proposed to take full advantage of the mineral resources of that country and the programme is of a far-reaching character. It is designed to include the financing of mineral and industrial development, the avoidance of monopolisation, and the development of additional power facilities to meet war requirements. The large-scale development of low-grade ores is an important part of the plan of action upon which considerable progress has already been made, the major points of which are :—

1. To solve the problem of securing wide and general use of new processes, to accomplish which it is expected that the Bureau of Mines will push its work to a triple-speed basis on the development of means for the processing of low-grade manganese ores, or alunites and magnesites ; plants to use new iron ore reduction processes producing sponge iron for later smelting ; economical extraction of such metals as copper, lead and zinc from America's abundant resources of low-grade ores ; and increased production of the alkali and alkaline earth metals—lithium, sodium, strontium, barium, and beryllium.

As part of this general problem, all enemy alien patents and processes are to be examined and tested, while all American-owned patents and processes for minerals needed for winning the war will be made available for the confidential use of the Bureau of Mines in order that the most effective processes can be recommended.

2. To break the second major bottleneck in obtaining ores which have been considered strategic and ores not previously considered strategic, it is proposed that funds be made available for exploratory work by the Bureau of Mines and Geological Survey for copper, iron, chromite, zinc and lead, involving the assignment of 250 additional engineers and geologists to intensify exploratory work in low-grade areas.

3. To break the third major bottleneck of securing capital for the development of short-lived or low-grade ore bodies it is proposed that power be given to grant loans to companies or individuals seeking to develop low-grade ores or contracting mills or smelters for the production of these essential war minerals. If private enterprise or competent management are not forthcoming, it is proposed that the Bureau of Mines be allowed to develop the mines, mills or refineries and be given the same long-term contracts as are offered to private enterprise.

4. Recommendations for manganese development sufficient to produce 2,683,000 long tons of manganese metal, enough for 429,000,000 tons of steel, and providing for the establishment of eight large milling plants, three hydro-metallurgical processing plants, and one matte smelting plant ; all of which would save 1,112,680 tons of shipping per year from Brazil and Cuba to the United States. Deposits in thirteen districts of eight states would furnish the necessary ore tonnage.

5. Recommendations for the revision of aluminium manufacturing practices to make the fullest possible use of new processes developed by the Bureau of Mines, which utilise common domestic shales, natural alums, leucites, glaucanite sands, feldspars and aluminium-bearing tailings from porphyry copper deposits to produce alum in small plants. The alum can be shipped to large centrally located plants for conversion into alumina by the use of another process recently developed by the Bureau of Mines.

6. Three new processes for the production of magnesium are reported to be in their final stages of development by the Bureau of Mines, in addition to other processes which extract magnesium from widely occurring rock formations instead of the usual sea-water or relatively scarce deposits of magnesite. If put into wide use, these processes will permit the production of magnesium by processes not privately controlled, and will ensure the continuation of the magnesium industry after the war period on a non-monopolistic basis.

7. Low-grade chromites, capable of producing 1,000,000 tons of metallurgical grade concentrates for chromium production, can be utilised when processes being developed by the Bureau of Mines are put into productive use. About 250,000 tons of this grade concentrates were required in 1941.

8. Recommendations for further exploration of carnotite deposits to supply most of the needs for vanadium for tool steels, and development of methods of vanadium recovery. Additional vanadium can be obtained from the very large known reserves of titaniferous magnesite which occur particularly in California.

Considerable attention is also given to the electric power needs for processing and fabricating minerals for the war programme, and there are strong indications that the demands to ensure the successful accomplishment of this programme are not being underestimated.

North-East Coast Institution of Engineers and Shipbuilders

AT the recent annual general meeting of the above Institution, the following elections to the Council were announced : President : Mr. J. Ransay Gebbie ; Vice-Presidents : Dr. T. W. F. Brown, Mr. A. J. Hendin, Mr. P. L. Jones, Mr. W. E. Loveridge, and Mr. Thomas Shaw ; Members of Council : Mr. D. Somers Brown, Mr. H. C. Forster, Mr. G. E. Jenkins, Mr. W. Spencer Paulin, Mr. Keith S. M. Scott, Mr. M. G. S. Swallow, and Mr. W. R. G. Whiting : Hon. Treasurer : Mr. W. H. Pilmour.

At this meeting Sir Amos L. Ayre was elected an Honorary Fellow of the Institution, in recognition of his distinguished work in connection with shipbuilding and its associated trades.

Colorimetry in Metallurgical Analysis

COLORIMETRIC methods of chemical analysis are fairly widely used, but their application in metallurgical determinations is quite limited, largely because of limited accuracy and interfering elements. Colorimetric methods, however, which are characterised by the speed with which a determination can be made, may be effectively used in metallurgical analysis if the colour measurement is made by a spectrophotometer. This instrument, until recently, has been more used by physicists than analytical chemists on account of its cost and design.

An absorption spectrophotometer which is quite distinct from a spectroscope is an instrument designed to produce light of any single wave-length—i.e., monochromatic—and to pass light of that wave-length through a sample which in analytical chemistry is usually a solution, and to measure the percentage of light passing through. While colours may be matched by the human eye, modern spectrophotometers are simple, compact, highly accurate instruments in which the absorption is measured by means of a photo-electric cell in connection with a galvanometer. White light is composed of light of different wave-lengths or different colours, and a solution appears coloured owing to the absorption of certain wave-lengths and the transmission of others. The amount of light absorbed is a function of the concentration of the coloured component in the solution, so that quantitative data can be obtained.

TABLE I.
ANALYSES OF BUREAU OF STANDARDS STEELS FOR MANGANESE.

No.	Chromium Present, %	Manganese Present, %	Manganese Found, %	Difference, %
111	0·272	0·66	0·65	−0·01
106	1·29	0·48	0·48	0·00
73	13·93	0·28	0·28	0·00

TABLE II.
ANALYSES OF BUREAU OF STANDARDS STEELS FOR CHROMIUM.

No.	Chromium Present, %	Chromium Found, %	Difference, %
111	0·272	0·30	+0·028
106	1·29	1·28	−0·01
73	13·93	13·90	−0·03

TABLE III.
ANALYSES OF CHROMIUM STEELS.

No.	Chromium Present, %	Chromium Found, %	Difference, %
1	0·27	0·28	+0·01
4	1·29	1·30	+0·01
8	5·57	5·52	−0·05
11	10·50	10·50	−0·00
13	13·93	13·90	−0·03
16	18·33	18·35	+0 02

One of the few colorimetric determinations in metallurgical analysis is for manganese, but it is one which is not widely applied. Chromium is sometimes determined colorimetrically in steels, but only when present in small amounts such as residual chromium. An investigation which has been carried out recently by Silverthorn and Curtis* at the Battelle Memorial Institute, Columbus, Ohio, on an accurate, rapid colorimetric method permits the determination of either manganese or chromium or both in plain carbon or alloy irons and steels without a preliminary separation of the manganese or chromium. Such a determination depends on the spectrophotometric method and is carried out in approximately 15 mins. with an accuracy of about 1%.

In this method of analysis, manganese and chromium absorption curves were first prepared using a solution containing potassium permanganate for the former and a solution containing chromium oxide for the latter. From these curves a wave length of 575 millimicrons, a point of high absorption was selected to make the standard graph for manganese, as chromium did not interfere with manganese at this wave-length. A standard graph for chromium was prepared with a 450 millimicrons wave-length, but as manganese, when present, interfered with chromium at this wave-length a correction curve for manganese had to be added to the graph. Using these curves, determinations were carried out on manganese in plain carbon steels, cast irons, chromium steels, and tungsten steels, and on chromium in chromium steels, and procedures recommended for routine determinations. Some of the results obtained on standard steel samples and on chronium steels are given in Tables I, II and III.

Metals and Alloys, 1942, vol. 15, No. 2, pp. 245–248.

Wood Replaces Coal at Swedish Steelworks

THAT the Swedish steel industry is facing great problems in respect of fuel supply under present conditions is indicated by Mr. Wiking Johnsson, the director of the Swedish Ironmasters' Association. The normal requirements of the Swedish iron and steel works of coal are about 700,000 tons per annum, but owing to the scant supply of coal about 60% of this fuel has had to be replaced by wood for quite a long time. When considering that for 1 ton of coal 7 cub. metres (247 cub. ft.) of cordwood must be procured, it is easy to understand that the trade has been faced with a bigger problem. The furnaces of the Swedish iron and steel works are generally designed for coal or oil-firing, and important alterations therefore have had to be made to adapt them for wood fuel. However, on the whole, this problem has been quite satisfactorily solved. On the other hand, changes in this respect have contributed to increase production costs very materially and in certain cases also resulted in a lower output. The supply of wood in some quarters is, moreover, scanty.

A very large portion of the pig-iron production in Sweden is based on coke. Thanks to the large stocks of coke laid up by the State Reserve Board at the outbreak of the war, and a fairly good supply since, the pig iron production has so far been maintained quite well.

The efforts to increase the production of charcoal pig iron have encountered great difficulties owing to the insufficient charcoal output. Since the complete conversion of motor traffic to charcoal-gas or wood-gas fuel, strong competition has arisen in the charcoal market. The automobiles in Sweden are now computed to be an even larger consumer of charcoal than the country's ironworks.

Mr. Johnsson mentions the fact that, while Sweden exports considerable quantities of high-grade steel in normal times, she simultaneously imports large quantities of structural and other mild steel, the imports of such steel during the years preceding the war amounting to about 450,000 tons annually. Only part of this quantity can now be obtained from abroad, which constrains the Swedish works to supply some of the deficiency and thus turn out more steel of ordinary grades than in normal times.

The Metallurgists' Note Book

THIS note-book embraces a collection of useful information and data specially prepared for metallurgists. It is arranged on the loose-leaf principle, and consists of a series of papers. It is designed to enable metallurgists to obtain, at reasonable cost, just that information which they require without entailing the purchase of publications which often contain much unwanted technical matter. The sheets are punched for filing in the binder supplied by the publisher, and in this way a handy reference book may be compiled. The papers so far published number about thirty, and deal with iron, steel and ferro-alloys; coal and coke; filters and filtration; and foundry sand.

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Notched Bar Sensitivity, Hardness, and Tensile Strength of Alloy Steels at Low Temperatures

KNOWLEDGE of the behaviour of materials at low temperatures is becoming increasingly important; it is important, for instance, to know whether these materials have capacity for plastic deformation at these temperatures, which would permit high local stresses and impacts without fracture. According to Pomp, Krisch and Haupt, this can best be proved by notched-bar tests. It is, however, also of great value to know the effect of low temperatures on mechanical properties, such as hardness and tensile strength, especially whether the same relations exist as for normal and high temperatures represented by the formula $H = c \times \delta\beta$, where H is the Brinell hardness, $\delta\beta$ the tensile strength, and c a constant between 0·34 and 0·36.

Two series of investigations have been carried out* on 62 different materials, of which 40 were low-alloyed chrome-molybdenum, chrome-molybdenum-vanadium, chrome-nickel, chrome-nickel-molybdenum, chrome-nickel-tungsten, chromium and nickel steels, 18 austenitic nickel, chrome-nickel, chrome-manganese, and chrome-manganese-silicon steels, as well as soft iron, nickel, copper and lead.

Notched-bar sensitivity was determined at + 20° C., at the temperature of liquid air, and between these two limits. All steels which retained a notched-bar sensitivity of more than 3 mkg./cm.² (about 140 ft.-lb. per sq. in.) at — 183° C., as well as copper and lead, were also tested in liquid hydrogen.

The experiments showed that some nickel, chrome-nickel, and chrome-manganese steels, especially those of austenitic structure, and metals such as nickel, copper and lead, still retained a large capacity for plastic deformation at the temperature of liquid hydrogen. Without exception, the low-alloyed martensitic steels showed a decrease of the notched-bar sensitivity down to — 183° C., the steels with additions of nickel giving the highest figures for impact strength. In addition, however, chrome-molybdenum steels, with or without nickel, showed impact strength figures up to 5 mkg./cm.² (about 232 ft.-lb. per sq. in.). Steels tempered to a high strength generally had a lower notched-bar sensitivity at low temperatures. Soft iron became extremely brittle at low temperatures, and the impact strengths of copper and lead increased with decreasing temperatures.

The hardness of all the 62 materials increased with decreasing temperatures, but this increase was proportionately small with those of higher hardness at a temperature of + 20° C.; the chemical composition also had an influence on the amount of the increase. Lead and soft iron showed the greatest change in hardness.

Tensile tests were made on some of the chrome-molybdenum, chrome-molybdenum-vanadium, chrome-nickel-molybdenum and the nickel steels, as well as on copper and lead at temperature of 20° and — 183° C., and in some cases at temperatures between these limits. In conformity with other workers, it was found that the 0·2 limit and the tensile strength increased with decreasing temperature, and the amount of this increase depended on the tensile strength at 20° C. The elongation at fracture was almost independent of temperature, while the contraction decreases to half the amount at 20° C. The marks made on specimens for the determination of elongation caused fracture in some cases, but were without influence in others.

As far as chrome-molybdenum, chrome-nickel-vanadium, and chrome-nickel-molybdenum steels were concerned, an increase in the ratio of tensile strength to hardness at — 183° C. could not be proved as the figures obtained were within the limits of the experimental defects.

* A. Pomp, A. Krisch and G. Haupt. Mitteilungen des Kaiser-Wilhelm Institut für Eisenforschung zu Düsseldorf, vol. 21, No. 15.

Reviews of Current Literature

Tin Solders

A Modern Study of the Properties of Tin Solders and Soldered Joints

TEN years ago the British Non-Ferrous Metals Research Association, having carried out investigations on tin solders and the requirements they have to meet in service, published a book entitled "Tin Solders: A Modern Study of the Properties of Tin Solders and Soldered Joints." The book, written by Mr. S. J. Nightingale, who conducted the investigation, enjoyed great popularity.

Since that time further work on the subject has been carried out in the B.N.F.M.R.A. laboratories and elsewhere, the Association's investigations being mainly concerned with the creep properties of solders (including antimonial solders) and of soldered joints. Dr. O. F. Hudson has revised and considerably expanded the book to include this new matter, and a second edition is now published. Recent events, which have made us look to our tin supplies and consider ways of economising in the use of tin, will make it necessary to modify the compositions of solders used for some purposes. This can only be done efficiently if based on a sound knowledge of the properties and behaviour of existing tin solders and of the reasons determining the suitability of particular compositions for different purposes. The new edition therefore appears at an opportune moment. It is set out in two parts. The first part deals with the constitution of the tin solders: the structure of solders; the mechanical properties of the solder alloys; the strength of soldered joints; creep properties of solder alloys and soldered joints; and alloying between the solder and the joint members. The second part deals with practical considerations (such as fluxes, the wiped joint, etc.) and the choice of a solder. There are numerous illustrations and photomicrographs.

By S. J. Nightingale. *Second Edition*, revised by O. F. Hudson, D.Sc. Published by the British Non-Ferrous Metals Research Association, Euston Street, London, N.W. 1. Price 10s. 6d. post free (in the United States $2.75).

THE Proprietors of the Patent No. 515043, for Improvements in the production of Metallic Screens by electro-deposition, are desirous of entering into arrangements by way of licence and otherwise on reasonable terms for the purpose of exploiting the same, and ensuring its full development and practical working in this country. All communications should be addressed in the first instance to Haseltine Lake & Co., 28, Southampton Buildings, Chancery Lane, London, W.C. 2.

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